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# NATIONAL STATUS AND TRENDS, MUSSEL WATCH PROGRAM

## A 2015 Assessment of Legacy Organic Contaminants in the Chesapeake Bay, MD

August 2023

NOAA TECHNICAL MEMORANDUM NOS NCCOS 318

NOAA NCCOS Monitoring and Assessment Branch

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## Disclaimers

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Site CBSV-1, credit: NOAA
Andrew Mason preparing caged mussels at site CBSV-3, credit: NOAA
Site CBSV-3, credit: NOAA
Dr. Dennis Apeti collecting field data, credit: NOAA

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Chesapeake Bay, MD, credit: NOAA

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## A 2015 Assessment of Legacy Organic Contaminants in the Chesapeake Bay, MD

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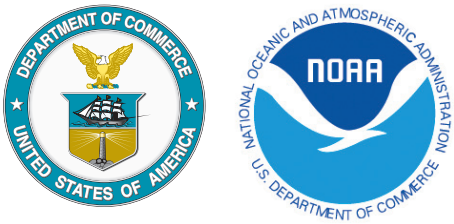



NOAA Technical Memorandum NOS NCCOS 318


| United States Department of Commerce | National Oceanic and Atmospheric Administration | National Ocean Service |
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# Abstract

Since 1986, the National Centers for Coastal Ocean Science's (NCCOS) National Status and Trends (NS&T) Mussel Watch Program (MWP) has monitored the nation's coastal waters for chemical contaminants and biological indicators of water quality. Beginning in 2014, NCCOS undertook the task of redesigning the MWP to focus on a rotating regional model in order to cater to regional and local scientific data and information needs. Using the MWP's regional design paradigm, the Chesapeake Bay study focused on the use of wild oysters at historic MWP monitoring sites and caged oysters at new, targeted, riverine sites. The combination of historic and targeted sites provided the potential to better understand land-use influence on the distribution of the contaminants being measured. Five historic MWP sites and fifteen river-based sites were selected for sampling including four sites in each of the Patapsco, Rhode and Choptank Rivers and three sites in the Severn River. Due to the lack of abundant oyster beds in most of these rivers, caged oysters purchased from a local grower were deployed at these sites for a two-month exposure. A total of 200 organic contaminants were analyzed and grouped into ten classes of compounds including Total Butyltins, Total Chlordanes, Total Chlorobenzenes, Total DDT, Total Dieldrins, Total Endosulfans, Total HCHs, Mirex, Total Polycyclic Aromatic Hydrocarbons (PAHs) and Total Polychlorinated Biphenyls (PCBs). Results indicated that most of the chemical contaminants were detected at various concentrations in oyster tissue, except Total Endosulfans, which were below detection limits at all of the survey sites. Total concentrations of several contaminants including those that have been banned since the 1970's continue to be found at levels above some federal guidelines in the Chesapeake Bay ecosystem. Contaminant concentrations showed a spatial pattern that highlighted land-use influence on the distribution of the contaminants in the study area. Concentrations of some contaminants, such as Total Butyltins, Total Chlordanes, Total DDT, Total Dieldrins, Total PAHs and Total PCBs, were significantly higher at survey sites located in industrial and heavily urbanized locations. Temporal trend analyses showed that concentrations of legacy organic contaminants are decreasing over time, a likely indication of positive impacts from management and mitigation activities. However, the persistence of these toxic chemicals above established threshold levels represents continued ecotoxicity concerns in the Chesapeake Bay, thus justifying the need for continued monitoring while state and federal organizations continue mitigation and restoration efforts of degraded habitats and water quality in the bay. This MWP study provides relevant scientific data on the magnitude and distribution of chemical contaminants that could be leveraged for baseline information and fills data gaps identified by resource managers in support of restoration efforts in the Chesapeake Bay.

# Table of Contents

# Commonly Used Acronyms

| | |
|---|---|
| DDT | Dichlorodiphenyltrichloroethane |
| g | gram |
| HCH | Hexachlorocyclohexane |
| MDL | method detection limit |
| µg | microgram |
| MWP | Mussel Watch Program |
| NS&T | National Status & Trends |
| ng | nanogram |
| NOAA | National Oceanic and Atmospheric Administration |
| PAH | Polycyclic aromatic hydrocarbon |
| PBDE | Polybrominated diphenyl ether |
| PCB | Polychlorinated biphenyl |

## 1.0 INTRODUCTION

Since 1986, the National Centers for Coastal Ocean Science's (NCCOS) National Status and Trends (NS&T) Mussel Watch Program (MWP) has monitored the nation's coastal waters for chemical contaminants and biological indicators of water quality. The program was established by the National Oceanic and Atmospheric Administration (NOAA) in response to a legislative mandate under Section 202 of Title II of the Marine Protection, Research and Sanctuaries Act (MPRSA) (33 USC 1442), which called on the Secretary of Commerce to, among other activities, initiate a continuous monitoring program "to assess the health of the marine environment, including monitoring contaminant levels in biota, sediment and the water column." With a goal to "deliver ecosystem science solutions" in support of coastal and marine ecosystem management nationwide, NCCOS supports the MWP to conduct environmental monitoring, assessment, and research in order to describe the status and trends of pollution in our nation's marine and coastal waters. The MWP utilizes an ecosystem-based approach to monitoring by collecting and analyzing sediment and bivalves (oysters and mussels) as surrogates for water pollution and bioaccumulation. The ability of sediments and bivalves to integrate anthropogenic contaminants over time makes them excellent candidates for determining the presence and relative concentrations of chemical stressors in the environment. In coastal zones around the US, including the Great Lakes and territories such as Hawaii and Puerto Rico, the MWP has established a network of 300 historical monitoring sites where nearly 600 organic and inorganic contaminants are monitored. Contaminants historically monitored by the MWP include legacy organic chemicals such as organochlorine pesticides (e.g. DDT), industrial contaminants (e.g. polychlorinated biphenyls), fossil fuel combustion byproducts (e.g. polycyclic aromatic hydrocarbons), and heavy metals (e.g. mercury).

The national MWP continues to improve its monitoring approaches and provide actionable information to stakeholders and the scientific community. However, recent funding constraints have required NOAA to re-examine the scope and scale of the MWP while still meeting its mandated requirements to monitor the coastal environment. Thus, beginning in 2010, NCCOS undertook the task of re-designing the MWP to focus on a rotating regional model in order to better address regional and local scientific data and information needs. As part of the re-design, NCCOS and the MWP have also invested resources in the assessment of the magnitude and distribution of contaminants of emerging concern (CECs) for long term monitoring consideration.

Using the MWP's regional design paradigm, this study focused on contaminant concentrations in oysters (*Crassostrea virginica*) in the Chesapeake Bay. The study combined the collection of wild oysters at historic MWP monitoring sites and caged oysters at new targeted sites. The combination of historic and targeted sites was designed in order to assess land-use influence on the distribution of the contaminants in the study area. The Chesapeake Bay study area (Figure 1) was selected for this study because 1) the bay represents an important estuarine environment that encompasses a NOAA focus area that has been subjected to congressional mandated restoration efforts, 2) the presence and spatial distribution of historic MWP monitoring sites, and 3) the available opportunity to leverage resources and build stronger collaborations among NCCOS' science divisions, as well as with state and local resource managers in Maryland. The project benefited from the expertise of scientists at NCCOS' Cooperative Oxford Laboratory and the Maryland Department of Natural Resources (MD-DNR), as well as a network of citizen groups such as Marylanders Grow Oysters and the Chesapeake Bay River Keepers. The study was designed to respond to chemical contamination data needs for local managers and citizen science groups by tailoring the study design to maximize its effectiveness while meeting MWP goals.

Chesapeake Bay is the largest estuarine system in the continental United States, and is home to critical wildlife habitats and important fisheries (NOAA, 2021). However, centuries of land development, agricultural, and industrial activities have caused damaging levels of pollution in the bay and its tributaries (Hartwell and Hameedi, 2007; Black et al., 2017). Extensive sedimentation and hypoxic conditions

(Newell, 1988), along with elevated toxic chemical concentrations (US EPA et al., 2012; CBF, 2022) have compounded to cause degraded water quality in the bay. Since the early 1980's, Federal and state resources have been supporting clean-up and ecological restoration efforts of the bay, however recent findings indicate that 72 percent of the Bay's tidal-water tributaries are still classified as fully or partially impaired under the Federal Clean Water Act (MDE, 2004), and that as a result of high concentrations of toxic contaminants, some areas of the Bay watershed are subjected to fish-consumption advisories (US EPA et al., 2012). Hence, sustained monitoring efforts of the status and trends of stressors, including chemical contaminants, are needed to provide a broad understanding of ecosystem dynamics in the Chesapeake Bay.

The overall goal of this effort was to assess the state of coastal contamination and ecosystem health in the study area. Specific objectives included: 1) analyze organic contaminants such as PAHs, PCBs, Butyltins, DDTs and other chlorinated toxic pesticides in oysters as a measure of water quality, 2) augment historic MWP monitoring sites with new targeted sites, 3) assess how different land-use categories may influence the magnitude and distribution of the organic contaminants, and 4) assess the temporal trends of the organic contaminants using the historic MWP sites.


**Figure 1. Map of the Chesapeake Bay, MD, showing the general location of the study area.**

The study resulted in coastal legacy organic contaminants data that supports the current MWP rotating regional monitoring approach and provides relevant scientific data to support resource managers and restoration efforts in the Chesapeake Bay.

## 2.0 MATERIALS AND METHODS

### 2.1 STUDY AREA

The Chesapeake Bay study included four tributaries (the Choptank, Patapsco, Rhode, and Severn Rivers) (Figure 1) which were selected based on their differing land-use categories (agricultural, heavy urban/industrial, forested/suburban, and urban respectively) (Table 1). Fifteen river-based sites were selected for sampling including four sites each in the Patapsco, Rhode and Choptank Rivers and three sites in the Severn River (Figure 2). Due to the lack of abundant oyster beds in most of these rivers, caged oysters purchased from a local grower were deployed at these sites. The locations of all deployed oysters were either mesohaline or polyhaline, therefore salinity at the targeted riverine sites was high enough to sustain oyster growth.

The MWP has 14 historic monitoring sites located in the Chesapeake Bay. To compare the historic open water sites against the riverine sites, 5 of the 14 historical sites were selected based on their proximity to the rivers where caged oysters were deployed. These sites were primarily in the mainstem of the bay or close to the mouth of the tributaries selected for this study. Wild oyster samples were collected at each of these historic sites. Field data from the collection of wild oysters and the deployment and retrieval of caged oysters can be found in Appendix 1.

**Table 1. Site location and sampling data from tissue samples in the Chesapeake Bay, MD.**

| Site Name | Matrix | Specific Location | Latitude | Longitude | Land-use Category |
|---|---|---|---|---|---|
| Choptank-1 | caged oyster (CV) | LaTrappe Creek | 38.65124 | -76.09811 | agriculture |
| Choptank-2 | caged oyster (CV) | Island Creek | 38.66423 | -76.13267 | agriculture |
| Choptank-3 | caged oyster (CV) | Island Creek | 38.67537 | -76.10911 | agriculture |
| Choptank-4 | caged oyster (CV) | Broad Creek | 38.72881 | -76.23573 | agriculture |
| Patapsco-1 | caged oyster (CV) | Riviera Beach | 39.16925 | -76.50734 | heavy urban/industrial |
| Patapsco-2 | caged oyster (CV) | Bear Creek | 39.24897 | -76.49134 | heavy urban/industrial |
| Patapsco-3 | caged oyster (CV) | Curtis Bay | 39.22500 | -76.56327 | heavy urban/industrial |
| Patapsco-4 | caged oyster (CV) | Masonville Cove | 39.24464 | -76.59678 | heavy urban/industrial |
| Rhode-1 | caged oyster (CV) | Locust Point | 38.87605 | -76.51576 | forested/suburban |
| Rhode-2 | caged oyster (CV) | O'Neill Island | 38.88062 | -76.53606 | forested/suburban |
| Rhode-3 | caged oyster (CV) | Forrest Branch | 38.88559 | -76.54160 | forested/suburban |
| Rhode-4 | caged oyster (CV) | Sellman Creek | 38.89943 | -76.53891 | forested/suburban |
| Severn-1 | caged oyster (CV) | Harbor Marina | 38.95974 | -76.47249 | urban |
| Severn-2 | caged oyster (CV) | Back Creek | 38.96858 | -76.47571 | urban |
| Severn-3 | caged oyster (CV) | Spa Creek | 38.97328 | -76.48536 | urban |
| CBBH | wild oyster (CV) | Brick House | 38.93860 | -76.37976 | open water |
| CBBO | wild oyster (CV) | Bodkin Point | 39.15541 | -76.40548 | open water |
| CBCP | wild oyster (CV) | Choptank River | 38.60978 | -76.11631 | open water |
| CBMP | wild oyster (CV) | Mountain Point | 39.08279 | -76.41517 | open water |
| CBSB | wild oyster (CV) | Simmons Bar | 38.32589 | -76.40762 | open water |

Notes: CV, *Crassostrea virginica*

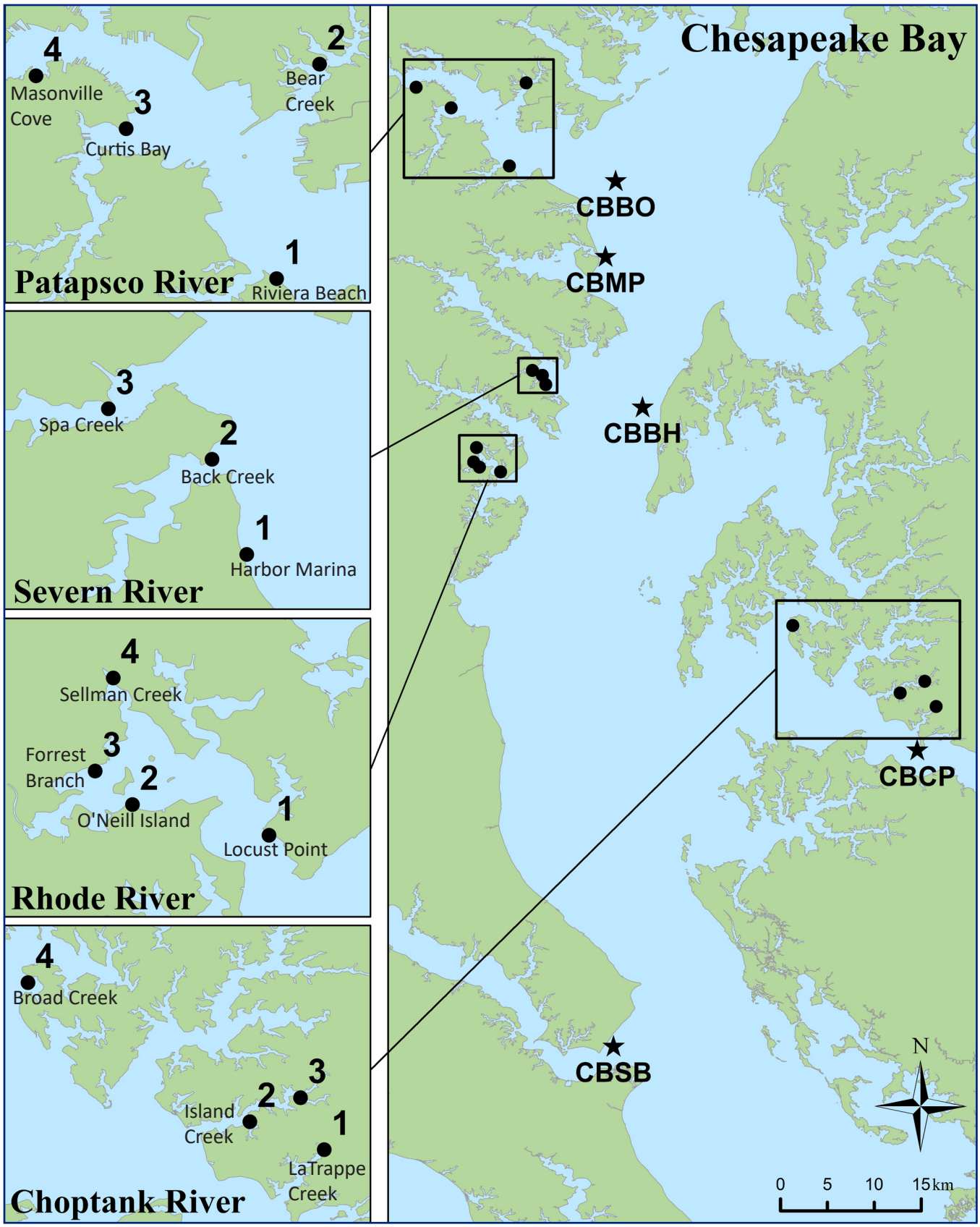


**Figure 2. Sampling sites in the Chesapeake Bay, MD. Round dots indicate targeted riverine site with caged oysters; stars represent historic Mussel Watch sites where wild oysters were collected.**

# Methods

**Chesapeake Bay Facts**

- The Chesapeake Bay is the largest estuary in the contiguous United States.
- The Bay's watershed covers over 64,000 square miles, and includes parts of six states.
- The human population in the Chesapeake Bay watershed, currently estimated at 18.1 million people, has risen by over 110% since 1950 and is projected to exceed 21 million people by the year 2040 (US EPA, 2016).
- Centuries of land development, agriculture and industrial activities have caused degraded water quality as a result of toxic chemical pollution, extensive sedimentation and hypoxia conditions in the bay and its tributaries (Hartwell and Hameedi, 2007; Newell, 1988; US EPA et al., 2012).

## Oyster Deployment Tributaries

*Choptank River*

- The Choptank River was selected due to extensive agricultural land use in its watershed.
- The four sample locations from this river were distributed between three smaller tributaries that feed into the lower Choptank: one in LaTrappe Creek (#1), two in Island Creek (#2 and #3) and one in Broad Creek (#4).

*Patapsco River*

- The Patapsco was selected due to heavy urbanization, including the City of Baltimore, and industrial complexes in its watershed.
- Four locations in the Patapsco were identified where salinity was sufficient for oyster survival and growth: Riviera Beach (#1), Bear Creek (#2), Curtis bay (#3) and Masonville Cove (#4).
- The Patapsco has been recognized by the Chesapeake Bay Program as one of only three 'Regions of Concern', meaning that chemical contaminants have been found at concentrations above thresholds associated with adverse effects and that these chemicals appear to be causing toxic effects on living resources (US EPA, 1999).

*Rhode River*

- The Rhode River was selected to represent low development land use. It primarily contains forested, light-residential and suburban areas.
- Deployed oysters were placed at four locations spread throughout the river: Sellman Creek (#4), across from Locust Point (#1), near O'Neill Island (#2) and in Forrest Branch (#3).
- Previous studies of benthic condition in the Rhode River have noted variable chemical contaminant levels with some mainstem sites containing chemical contaminants at high concentrations, particularly for metals and PAHs (Fulton et al., 2007; Leight et al., 2011).

*Severn River*

- The lower Severn River was selected as an urbanized watershed with hardened shorelines and extensive marinas. It drains large sections of the city of Annapolis and the Naval Academy grounds.
- Oysters were deployed in cages at three locations in the Severn River: downstream along the southern shore of the Severn in the Chesapeake Bay Harbor Marina (#1), Back Creek (#2) and Spa Creek (#3).
- Benthic sediments in the area have been shown to contain metals, PAHs, and legacy pesticides, leading to its classification as an 'Area of Emphasis' by the Chesapeake Bay Program, where chemical contaminant data are at increased concentrations above thresholds associated with adverse effects, but where there is limited or no evidence of actual effects (US EPA, 1999).

## 2.2 SAMPLING DESIGN

Sampling methods followed the MWP's standard field protocols (Apeti et al., 2012). The MWP field activities are designed to have insignificant environmental impacts, and are in compliance with NOAA Administrative Order (NAO) 216-6A, Environmental Review Procedures under the status of the National Environmental Policy Act (NEPA). For this study, oyster samples were collected under the scientific collection permit SCP201581AB provided by the Maryland Department of Natural Resources (MD-DNR) Fisheries Service.

The oysters that were caged and deployed at the riverine sites were purchased from an aquaculture facility on the Chesapeake Bay and stored at the NCCOS Cooperative Oxford Laboratory (COL) in Oxford, Maryland for less than one week. The oysters were deployed from June 22-29, 2015, and suspended from piers at mid-water column depth (Figure 3). Approximately 40-50 oysters were placed in each cage and two cages were deployed at each site. The cages were borrowed from the MD-DNR - Marylanders Grow Oysters Program (MDNR, 2016). Approximately every 2-3 weeks the cages and oysters were cleaned with brushes to dislodge biofouling organisms and to check for any oyster mortality. Caged oysters were retrieved after two months of exposure between August 27-31, 2015. At each riverine site, a composite of about 80 individual oysters were collected as a site sample.

Wild oyster samples were collected at the five historic sites (Figure 2) using the NOAA research vessel R/V *Chesapeake* in August 2015. Oyster sampling from natural oyster bars was conducted by oyster dredge. Approximatively 50 individual wild oysters were composited as a site sample at each site.

Oyster samples were brush-cleaned, placed in double Ziploc bags and preserved on ice. Care was taken not to expose the specimen to boat exhaust and to prevent them from coming in contact with ice-melt freshwater. Samples were packed in ice chests and shipped to the analytical laboratory within two days of collection. In addition to chemistry data at each location, physical data was collected including the temperature, salinity, and dissolved oxygen at the surface and bottom of the water column and the water depth (Appendix 1).

**Figure 3. NCCOS scientist deploying caged oysters at a Severn River site.**

## 2.3. CHEMICAL ANALYSIS

The organic contaminants analyzed in this study are listed in Table 2, including: 64 polycyclic aromatic hydrocarbons (PAHs) analyzed using gas chromatography/mass spectrometry in the selected ion monitoring mode, 29 organochlorine pesticides and 83 polychlorinated biphenyls (PCBs) analyzed using gas chromatography/electron capture detection, and four butyltins analyzed using gas chromatography/flame photometric detection after derivatization. Detailed descriptions of the MWP standard analytical protocols, including quality assurance/quality control (QA/QC), can be found in Kimbrough et al. (2007).

The organic contaminants routinely monitored by the MWP are part of the EPA priority pollutants list of deleterious chemicals and are demonstrated to be toxic to aquatic biota and potentially to humans. An overview of each class of the chemical contaminants is provided below, including production status, application, environmental fate and transport, and environmental health effects.

Butyltins

For this document, Total Butyltins is the sum of three organometallic compounds: tributyltin (TBT), the parent compound, and two of its less toxic degradation by-products or metabolites, dibutyltin and monobutyltin. TBT has had a variety of uses ranging from a biocide in antifouling paints to a catalyst and an ingredient in glass coatings (Bennett, 1996; Birchenough et al., 2002). The butyltins can be highly toxic in multiple forms as they naturally degrade in the environment. TBT was first shown to have biocidal properties in the 1950's (Bennett, 1996; Evans, 1970). In the late 1960s, TBT was incorporated into an antifouling polymer paint system, quickly becoming one of the most effective paints used on boat hulls (Birchenough et al., 2002). In the aquatic environment, TBT is degraded by microorganisms and sunlight (Bennett, 1996). In terms of fate and transport, the half-life of TBT in ambient water is on the order of days (US EPA, 2003) and its degradation to monobutyltin (MBT) takes approximately a month. However, in deeper anoxic sediments, the half-life of TBT appears to be on the order of years (Batley, 1996).

The presence of TBT in the environment has been linked to endocrine disruption. In the mid-1970s, the use of TBT was linked to abnormal shell development and poor weight gain in oysters, and more recently to an imposex condition (females developing male characteristics) in marine gastropod mollusks (Batley, 1996; Strand et al., 2009). Beginning in 1989, the use of TBT as an antifouling agent was banned in the US on non-aluminum vessels smaller than 25 meters in length (Gibbs & Bryan, 1996). However, the continued use of TBT on ships and other antifouling paint applications increased the ubiquity of the compound in aquatic environments. Thus, TBT and its metabolites continue to be detected in many components of coastal and marine ecosystems in the US.

Chlordanes

Chlordane belongs to a group of organic pesticides called cyclodienes. It is a technical mixture whose principle components are alpha-chlordane, gamma-chlordane, heptachlor, and nonachlor. Chlordane as reported here is the sum of seven prominent compounds, including: heptachlor, heptachlor-epoxide, oxychlordane, alpha-chlordane, gamma-chlordane, trans-nonachlor, and cis-nonachlor.

Technical chlordane, an insecticide, was used in the US from 1948-1983 for agricultural and urban settings to control insect pests. It was also the predominant insecticide used for the control of subterranean termites. Agricultural uses were banned in 1983 and all uses were banned by 1988. These compounds are some of the most ubiquitous contaminants measured by the MWP. The US Food and Drug Administration (FDA) has established a safety level of 0.3 ppm wet weight for both chlordane and heptachlor/heptachlor epoxide in all fish (US FDA, 2011).

Human exposure to chlordane can occur through eating crops from contaminated soil, fish, and shellfish from contaminated waters or breathing contaminated air. Chlordane can enter the body by being absorbed through the skin, inhalation, and ingestion. At high levels, chlordane can affect the nervous

**Table 2. Chemical contaminants analyzed in oyster tissue from the Chesapeake Bay, MD.**

| Butyltins (n=4/3*) | HCHs (n=4) | PAHs (cont.) | PAHs (cont.) | PCBs (cont.) | PCBs (cont.) |
|---|---|---|---|---|---|
| Monobutyltin | Alpha-HCH | C1-Phenanthrenes/Anthracenes | Dibenzo(a,h)anthracene | PCB74/61* | **PCB167*** |
| Dibutyltin | Beta-HCH | C2-Phenanthrenes/Anthracenes | C1-Dibenzo(a,h)anthracenes* | **PCB77*** | **PCB169*** |
| Tributyltin | Delta-HCH | C3-Phenanthrenes/Anthracenes | C2-Dibenzo(a,h)anthracenes* | **PCB81*** | PCB170/190 |
| Tetrabutyltin* | Gamma-HCH | C4-Phenanthrenes/Anthracenes | C3-Dibenzo(a,h)anthracenes* | **PCB82*** | **PCB172*** |
| Chlordanes (n=7/4*) | Mirex (n=1) | Dibenzothiophene | Benzo(g,h,i)perylene | **PCB83*** | PCB174* |
| Heptachlor | Mirex | C1-Dibenzothiophenes | PCBs (n=83/**39**/18*) | **PCB84*** | **PCB176/137*** |
| Heptachlor-Epoxide | PAHs (n=64/**58**/39*) | C2-Dibenzothiophenes | **PCB1*** | **PCB85*** | **PCB177*** |
| Oxychlordane* | cis/trans Decalin* | C3-Dibenzothiophenes | **PCB7/9*** | **PCB86*** | **PCB178*** |
| Alpha-Chlordane | C1-Decalins* | **C4-Dibenzothiophenes*** | PCB8/5 | PCB87/115* | PCB180 |
| Gamma-Chlordane* | C2-Decalins* | Fluoranthene | **PCB15*** | **PCB88*** | PCB183* |
| Trans-Nonachlor | C3-Decalins* | Pyrene | **PCB16/32*** | **PCB92*** | **PCB185*** |
| Cis-Nonachlor* | C4-Decalins* | C1-Fluoranthenes/Pyrenes | PCB18 | PCB95* | PCB187 |
| Chlorobenzenes (n=5) | Naphthalene | C2-Fluoranthenes/Pyrenes* | **PCB22/51*** | **PCB97*** | **PCB189*** |
| 1,2,3,4-Tetrachlorobenzene | C1-Naphthalenes | C3-Fluoranthenes/Pyrenes* | **PCB24/27*** | PCB99* | **PCB191*** |
| 1,2,4,5-Tetrachlorobenzene | C2-Naphthalenes | **C4-Fluoranthenes/Pyrenes*** | **PCB25*** | PCB101/90 | PCB194* |
| Hexachlorobenzene | C3-Naphthalenes | Naphthobenzothiophene* | **PCB26*** | PCB105 | PCB195/208 |
| Pentachloroanisole | C4-Naphthalenes | C1-Naphthobenzothiophenes* | PCB28 | **PCB107*** | **PCB196/203*** |
| Pentachlorobenzene | Benzothiophene* | C2-Naphthobenzothiophenes* | PCB29* | PCB110/77* | PCB199* |
| DDTs (n=6) | C1-Benzothiophenes* | C3-Naphthobenzothiophenes* | PCB31* | **PCB114/131/122*** | **PCB200*** |
| 2,4'-DDD | C2-Benzothiophenes* | **C4-Naphthobenzothiophenes*** | **PCB33/53/20*** | PCB118 | PCB201/157/173* |
| 4,4'-DDD | C3-Benzothiophenes* | Benz(a)anthracene | **PCB40*** | **PCB126*** | **PCB205*** |
| 2,4'-DDE | **C4-Benzothiophenes*** | Chrysene/Triphenylene | **PCB41/64*** | PCB128 | PCB206 |
| 4,4'-DDE | Biphenyl | C1-Chrysenes | **PCB42/59/37*** | **PCB129/126*** | PCB209 |
| 2,4'-DDT | Acenaphthylene | C2-Chrysenes | **PCB43*** | **PCB136*** | |
| 4,4'-DDT | Acenaphthene | C3-Chrysenes | PCB44 | PCB138/160 | |
| Dieldrins (n=3/2*) | Dibenzofuran* | C4-Chrysenes | PCB45* | **PCB141/179*** | |
| Aldrin | Fluorene | Benzo(b)fluoranthene | **PCB46*** | PCB146* | |
| Dieldrin | C1-Fluorenes | Benzo(k,j)fluoranthene | **PCB47/48/75*** | PCB149/123* | |
| Endrin* | C2-Fluorenes | **Benzo(a)fluoranthene*** | PCB49* | PCB151* | |
| Endosulfans (n=3) | C3-Fluorenes | Benzo(e)pyrene | PCB52 | PCB153/132 | |
| Endosulfan I | **Carbazole*** | Benzo(a)pyrene | PCB56/60* | PCB156/171/202* | |
| Endosulfan II | Anthracene | Perylene | PCB66 | PCB158* | |
| Endosulfan Sulfate | Phenanthrene | Indeno(1,2,3-c,d)pyrene | PCB70* | **PCB166*** | |

Notes: Sample size "n" represents the number of contaminants remaining after the corresponding contaminants have been removed. Bold, values were removed from the contaminant group totals when comparing to the Mussel Watch Program's 50th and 85th percentiles; *, values were removed from contaminant group totals when analyzing historic trends; DDT, dichlorodiphenyltrichloroethane; DDD, dichlorodiphenyldichloroethane; DDE, dichlorodiphenyldichloroethylene; HCH, hexachlorocyclohexane; PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl

system, digestive system, brain, and liver and is also carcinogenic. Chlordane is highly toxic to invertebrates and fish.

Removal from both soil and water sources is primarily by volatilization and particle-bound runoff. In air, chlordane degrades as a result of photolysis and oxidation. Chlordane exists in the atmosphere primarily in the vapor-phase, but the particle-bound fraction is important for long range transport. Chlordane is prevalent in the Arctic food web (Hargrave et al., 1992). Chlordane binds to dissolved organic matter further facilitating its transport in natural waters.

Chlorobenzenes

Chlorobenzenes belong to the family of organic halogen compounds and are widely used as degreasers, chemical intermediates and solvents for pesticide formulations, adhesives, paints, polishes, dyes and drugs. For example, pentachloroanisole comes from the biomethylation of pentachlorophenol, a chemical used as a general biocide by agriculture and other industries including textiles, paints, oil drilling and forestry (Canada, 2012). Although chlorobenzenes are not banned, their production has decreased by 60% since their peak in 1960 due primarily to regulations on DDT where it was used as part of the manufacturing process (ATSDR, 1990).

There is inadequate evidence to classify chlorobenzenes as carcinogens, however, animal studies indicate that livers, kidneys and the central nervous system are affected by exposure to chlorobenzenes (ATSDR, 1990). Chlorobenzenes typically evaporate rapidly into the air or are broken down by bacteria and are not considered to build up in the food chain.

Dichlorodiphenyltrichloroethane (DDTs)

Total DDTs (dichlorodiphenyltrichloroethane) is the name given to the sum of six compounds comprised of ortho- and para- forms of DDT and its transformation products dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD), the latter being the most predominant form found in the environment. DDT was used worldwide as an insecticide for agricultural pests and mosquito control. The use of DDT in the United States was banned in 1972, but it is still used in some countries today. Due to its persistence and hydrophobic nature, DDT bioaccumulates in organisms. Organochlorine pesticides are typically neurotoxins and DDT has been shown to interfere with the endocrine system (Rogan & Chen, 2005). DDT and its metabolite DDE were specifically linked to eggshell thinning in birds (Lincer, 1975). The US FDA has established a safety level of 5 ppm wet weight for DDT and DDE in all fish (US FDA, 2011).

DDT and its metabolites can be rapidly broken down by sunlight when in the air, however in soil they are slowly broken down by microorganisms. These chemicals can bioaccumulate in the fatty tissue of animals (ATSDR, 2002b). Evaporation of DDT from soil, followed by long distance transport, results in its widespread global distribution, i.e. the "grasshopper" effect (Wania and Mackay, 1996). DDT that enters surface waters is subject to volatilization, adsorption to suspended particulates and sediment, and bioaccumulation. About half of the atmospheric DDT is adsorbed to particulates (Bidleman, 1988).

Dieldrins

In this document, Total Dieldrins is defined as the sum of three compounds: dieldrin, aldrin, and endrin. Dieldrins were widely used as insecticides in the 1960s for the control of termites around buildings and general crop protection from insects. In 1970, all uses of dieldrins were banned based on concern that they could cause severe aquatic environmental impact as well as having potential carcinogenicity (US EPA, 1980). The ban was lifted in 1972 to allow limited use of dieldrins, primarily for termite control. In the US, all uses of dieldrins were finally banned in 1989 (EPA, 1990).

The predominance of dieldrin in the environment can be explained by the degradation of aldrin to dieldrin in the environment by sunlight and bacteria. Additionally, aldrin rapidly changes to dieldrin in plants and

animals. Dieldrins in water break down very slowly and once they enter an animal body, they are stored in fat and leave the body very slowly. Exposure humans to dieldrins occurs through ingestion of contaminated water and food products, including fish and shellfish, and through inhalation of indoor air in buildings treated with these insecticides. Acute and long-term human exposures are associated with central nervous system toxicity (ATSDR, 2002a).

Because dieldrins can build up in the body, health effects can occur after long periods of exposure to smaller amounts. Aldrin and dieldrin are carcinogenic to animals and classified as likely human carcinogens. The US FDA has established a safety level of 0.3 ppm wet weight for aldrin and dieldrin in all fish (US FDA, 2011).

Endosulfans

Endosulfan was a restricted-application pesticide, used to treat certain crops against aphids, beetles, leafhoppers, white flies, etc. (ATSDR, 2015). Endosulfan is a mixture of two isomers, referred to as endosulfan I and II. Endosulfan sulfate is a product of oxidation and can be found in technical grade endosulfan. Endosulfans can build up in the body of animals that live in contaminated water and have been shown to affect the nervous system. In water, endosulfan I and II change into the less toxic endosulfan diol, however endosulfan sulfate in more resistant to break down. The use of endosulfan was restricted to certain crops before its phase-out by 2016 (ATSDR, 2015).

Hexachlorocyclohexane (HCHs)

Hexachlorocyclohexane (HCH) is a mixture of eight or more stereoisomers used as an insecticide to protect crops. Technical grade HCH, contains the alpha, beta, gamma, delta and epsilon forms of HCH. Almost all of the insecticidal properties are found in gamma-HCH, also known as lindane, which is used as an insecticide on fruit, vegetables and forest crops. It can also be found in lotion, cream, or shampoo and as a prescription to treat head and body lice, and scabies (ATSDR, 2005).

All HCH isomers are toxic to animals to varying degrees and are persistent in the environment. In sediments and water, HCH can be broken down into a less toxic substance by algae, bacteria and fungi, however it is a slow process. Like other organochlorine compounds HCH can accumulate in the fatty tissue of fish. The Department of Health and Human Services (DHHS), International Agency for Research on Cancer (IARC) and the EPA vary in their classification of HCH as a human carcinogen. However, technical HCH, alpha-HCH, and beta-HCH are listed by all three as at least possible human carcinogens (ATSDR, 2005). In 2009, the Stockholm Convention on Persistent Organic Pollutants implemented an international ban on the use of lindane in agricultural applications but allowed a 5-year extension for its use in the treatment of head lice and scabies (UNEP, 2009). The US did not ratify the convention; however, the EPA requested the voluntary cancellation of the last agricultural uses of lindane in 2006 (US EPA, 2006). In 2015, based on a review of the most recent data on lindane, the IARC modified its classification from "probably carcinogenic to humans" to "known to cause human cancer" (IARC, 2015).

Mirex

Mirex was used as a flame retardant in rubber, plastic, paints, paper and electrical goods and to control fire ants from 1959 to 1972. It has not been manufactured or used in the US since 1978. Mirex breaks down slowly in the environment and any detected concentrations are probably due to residual chemicals rather than any new sources.

Polycyclic aromatic hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are found in creosote, soot, petroleum, coal and tar, and are the only organic contaminants measured by the Mussel Watch Program that have natural sources (e.g. forest fires, volcanoes, and natural seeps) in addition to anthropogenic sources (e.g. automobile emissions, home heating, coal fired power plants). Some PAHs are formed from the fusing of benzene rings during the incomplete combustion of organic materials. PAHs can also enter the aquatic environment

by means of discharge from industrial and wastewater treatments plants (ATSDR, 1995). The fate and transport of PAHs is variable and dependent on the physical properties of each individual compound. Most PAHs strongly associate with particles. High molecular weight (HMW) PAHs (composed of four or more aromatic rings) associate to a higher degree with particles relative to low molecular weight (LMW) PAHs (ATSDR, 1995). LMW PAHs predominate in petroleum products whereas HMW compounds are associated with combustion.

Made up of a suite of hundreds of compounds, PAHs exhibit a wide range of toxicities. While many aquatic organisms like fish can metabolize PAHs, marine invertebrates, such as oysters, are less able to efficiently metabolize them and as such can be better indicators of overall environmental exposure (Neff, 1985). The PAH contents of plants and animals may be much higher than PAH contents of soil or water in which they live (ATSDR, 1995). A number of the PAHs that bioaccumulate in aquatic and terrestrial organisms are toxic and some, including benzo(a)pyrene, benz(a)anthracene, chrysene, benzo(b) fluoranthene, benzo(k)fluoranthene, dibenzo(a,h)anthracene, and indeno(1,2,3-c,d)pyrene, are likely carcinogens (ATSDR, 1995). Toxic responses to PAHs in aquatic organisms include reproduction inhibition, mutations, liver abnormalities, and mortality. Exposure to aquatic organisms results from oil spills, boat exhaust, and urban runoff. There is no US FDA recommended safety level for PAHs in fish and fish products.

Polychlorinated biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are synthetic organic compounds that have been used in numerous applications including electrical transformers and capacitors, hydraulic and heat transfer fluids, pesticides, and in paints. PCBs have a biphenyl ring structure (two benzene rings with a carbon to carbon bond) and a varying number (1-10) of chlorine atoms. There are 209 individual PCB compounds (a.k.a. congeners). PCBs were manufactured in the US between 1929 and 1977. In the US, a single manufacturer produced all PCBs and the commercial products were referred to as Aroclors, which are mixtures of PCB congeners. Approximately 65% of PCBs manufactured in the US were used in electrical applications (Eisler & Belisle, 1996). Although no longer manufactured in the US, ecosystem contamination by PCBs is widespread due to their environmental persistence and tendency to bioaccumulate. In water, small amounts of PCB may remain dissolved, but the majority adhere to fine sediment and organic particles and can take years to degrade. Current pollution sources include volatilization from landfills, leaks from old electrical equipment, and dredging of contaminated sediments (WHO & IPCS, 1993).

PCBs readily accumulate in the tissues of organisms including filter feeders, fish, and marine mammals. They have been linked to many health issues including adversely affecting reproduction, growth, metabolism, and survival in animals (Eisler & Belisle, 1996). PCBs are associated with skin ailments, neurological, and immunological responses and at high doses can decrease motor skills and cause memory loss. Other effects can include hepatotoxicity, immunotoxicity, neurotoxicity, low birth weight, and teratogenicity (Eisler & Belisle, 1996). Exposure to PCBs in fish has been linked to reduced growth, reproductive impairment, and vertebral abnormalities (Eisler & Belisle, 1996). PCBs have also been shown to cause cancer in laboratory animals and are likely carcinogens in humans (ATSDR, 2000). The main human exposure route for PCBs is through eating contaminated seafood and meats, which is the reason for many consumption advisories. The US FDA safety level for PCBs in all fish (edible portion) is 2 ppm wet weight, irrespective of which mixture of PCBs is present (US FDA, 2011).

## 2.4 LIPID AND PERCENT MOISTURE MEASUREMENTS

Aliquots of approximately 1 to 2 g of homogenized field collected wet tissue were oven dried in the laboratory at 105°C to a constant weight. Percent moisture was determined by calculating the amount of mass lost during the drying procedure for each aliquot. The percent moisture was used to calculate the dry weight of the corresponding weighed wet aliquot. Dry weights were determined so that tissue

contaminant concentration could be reported in per gram dry weight (Appendix 2) (McDonald et al., 2006).

Tissue percent lipid was determined by weighing an aliquot of dichloromethane-extractable material. Tissues were extracted using a Dionex ASE200 Accelerated Solvent Extractor. The extract was concentrated to 3 mL and a 100 µL aliquot was removed and weighed to the nearest 0.001 mg on a pre-dried, tared glass fiber filter. Percent lipid was calculated based on weight of the aliquot, extract volume, and sample weight (Appendix 2) (McDonald et al., 2006).

## 2.5 DATA ANALYSIS

### 2.5.1 Data Processing

Laboratory results were subjected to regular NS&T performance-based quality assessment and quality control for data accuracy and precision. For each legacy organic compound measured, an analytical method detection limit (MDL) was determined (Appendix 3). Determination of MDLs followed procedures described by the Environmental Protection Agency in 40 CFR Part 136 (US EPA, 2007). The MDLs were defined as the Student's t value at 99% confidence level multiplied by the standard deviation of seven or more replicate measurements of the same low level spiked samples. Congeners and homologous organic compounds were grouped by classes of contaminants (Table 2) and the "totals" of each group were derived as the arithmetic sum of all the individual compounds. Although some of the individual compounds are discussed due to their outlier concentration or chemical and toxicological importance, all the statistics, data interpretation, and discussion were based on the "total" organic values.

### 2.5.2 Statistical Analyses

Data management and analysis were conducted using a combination of R packages, Microsoft Excel, ArcGIS, and Stata system statistical package. Concentrations were blank corrected and concentration values for individual chemical contaminant that were below the MDL were qualified as undetected and were assigned a value of zero. The final concentrations values of each class of chemical contaminants were reported as "total" concentrations, which were derived as the arithmetic sums of the value of individual homologues or congeners compounds (e.g. total PAHs). The total concentrations for each class of contaminants in oyster tissue were tested for normality using a Shapiro-Wilks normality test. Because the data was not normally distributed, nonparametric statistical approaches were utilized for data assessments. For each class of contaminants, differences in total concentrations for sites associated with different land uses (e.g. agricultural, heavy urban/industrial, forested/suburban, and urban) were analyzed using a Kruskal-Wallis test (nonparametric test on ranks). The historic MWP sites were not included in the land-use analysis to avoid comparing caged and wild oysters. When chemical concentrations from different land use classifications were identified as statistically different, they were compared using a Dunn's test of multiple comparisons using rank sums. Significance of statistical tests was reported at a probability level of 0.05.

In order to analyze trends, subsets of the total contaminants in some of the compound groups had to be calculated to reflect the historic analytical techniques (Table 2). Temporal trend analyses were conducted using the technique of moving average. Statistical moving average analysis is a smoothing operation that tends to remove fluctuations from time series data and highlights the overall temporal trends. For this study, 3-point moving averages of the yearly means were applied using R. For each chemical compound, in addition to site-specific assessments, the moving average technique was applied to aggregated annual data from all five long-term sites in the attempt to assess the bay-wide trends. Assessing the bay-wide temporal trends provided a better picture of chemical contaminant concentration increases or decreases over the monitoring years, and reflected the effectiveness of regulations that banned some toxic chemicals, and benefits of restoration and clean-up efforts.

### 2.5.3 Comparison to Guidelines

Contaminant concentration levels in oyster samples from this study were compared to the long-term MWP monitoring data, particularly the 50th and 85th percentile of national data for each group of contaminants (Table 3). The percentiles for oyster tissue were derived using the 2008-2009 MWP oyster data and represent the concentrations from 105 sites. The list of contaminants monitored by the MWP has increased over the monitoring years. For this reason, only contaminants that were historically measured in 2008/2009 were used to compare the Chesapeake Bay data to the national percentiles. In this study, 39 PCB congeners and 58 PAHs homologues were used for Total PCBs and Total PAHs calculations respectively when comparing to national percentiles (Table 2).

**Table 3. National 50th and 85th percentile concentration levels derived using 2008-2009 MWP data for oysters (all values in ng/dry g).**

| Percentile | Matrix | Total Butyltins | Total Chlordanes | Total Chlorobenzenes | Total DDTs | Total Dieldrins | Total Endosulfans | Total HCHs | Mirex | Total PAHs | Total PCBs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 50th | tissue | 0.00 | 4.03 | 0.33 | 6.84 | 0.94 | 0.00 | *na* | *na* | 137.50 | 15.26 |
| 85th | tissue | 40.04 | 17.18 | 1.29 | 20.26 | 3.30 | 2.59 | *na* | *na* | 715.98 | 75.34 |

Notes: DDT, dichlorodiphenyltrichloroethane; HCH, hexachlorocyclohexane; PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl

Additionally, contaminant concentrations in tissue were evaluated against the US FDA maximum permissible action levels for molluscan shellfish consumption for human health protection (US FDA, 2011) and the US EPA Screening Values (SVs) (US EPA, 2000) for recreational fishers. The US FDA Action and Tolerance Levels (Table 4) represent concentration limits at which US FDA will take legal action to remove shellfish from the market (US FDA, 2011) to protect human health. The US EPA SVs (Table 4) were developed to provide guidance to state, local, regional and tribal environmental health officials for their contaminant monitoring programs, and for issuing fish and shellfish consumption advisories (US EPA, 2000). The SVs represent a threshold concentration of concern for a chemical contaminant in fish and shellfish tissue for a critical toxic or a carcinogenic effect in humans. In cases where there were both carcinogenic and non-carcinogenic SVs available, the SV for the carcinogenic effects was used. Values higher than the SVs provide an indication of where more intensive site-specific monitoring and/or evaluation of human health risks should be conducted (US EPA, 2000). The US EPA and US FDA guideline values are reported on wet tissue weights basis, and where available for comparison, concentrations of chemical contaminants in oysters from the Chesapeake Bay were converted to wet weights using the percent dry fraction (Appendix 2).

**Table 4. US FDA Action and Tolerance levels and US EPA Screening Values (SVs) for chemical contaminants in fish and shellfish (ng/g wet weight) (US FDA, 2011; US EPA, 2000).**

| Compound | USFDA Action Level | USFDA Tolerance Level | USEPA Recreational Fishers Screening Values | | USEPA Subsistence Fishers Screening Values | |
|---|---|---|---|---|---|---|
| | | | Noncarcinogenic | Carcinogenic | Noncarcinogenic | Carcinogenic |
| Tributyltin | -- | -- | 1,200 | -- | 147 | -- |
| Aldrin or Dieldrin | 300 | -- | -- | 2.5 | -- | 0.307 |
| Endrin | -- | -- | 1,200 | -- | 147 | -- |
| Endosulfan (I and II) | -- | -- | 24,000 | -- | 2,949 | -- |
| Heptachlor/ Heptachlor epoxide | 300 | -- | -- | 4.39 | -- | 0.54 |
| Hexachlorobenzene | -- | -- | -- | 250 | -- | 3.07 |
| Lindane[a] | -- | -- | -- | 30.7 | -- | 3.78 |
| Mirex | 100 | -- | 800 | -- | 98 | -- |
| PAHs[b] | -- | -- | -- | 5.47 | -- | 0.673 |
| Total Chlordane[c] | 300 | -- | -- | 114 | -- | 14 |
| Total DDT[d] | 5,000 | -- | -- | 117 | -- | 14.4 |
| Total PCBs[e] | -- | 2,000 | -- | 20 | -- | 2.45 |

Notes: USFDA, US Food and Drug Administration; USEPA, US Environmental Protection Agency; DDT, dichlorodiphenyltrichloroethane; PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl

[a] Also known as Gamma-hexachlorocyclohexane or Gamma-HCH.

[b] The EPA recommendeds that tissue samples be analyzed for benzo(a)pyrene and 14 other PAHs (Acenaphthene, Acenaphthylene, Anthracene, Benz(a)anthracene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Benzo(g,h,i)perylene, Chrysene, Dibenz(a,h)anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-cd)pyrene, Phenanthrene, Pyrene) and that that a potency-weighted total concentration be calculated for each sample for comparison with the recommended SVs for benzo(a)pyrene.

[c] The total concentration of cis- and trans-chlordane, cis- and trans-nonachlor and oxychlordane.

[d] The total concentration of 4,4'- and 2,4'-DDT and their 4,4' and 2,4'-DDE and DDD metabolites.

[e] EPA recommends that 18 congeners be summed to determine total PCB concentration (8,18,28,44,52,66,77,101,105,118,126,128,138,153,169,170,180,187).

## 3.0 RESULTS AND DISCUSSION - ORGANIC CONTAMINANTS IN OYSTER TISSUE

The concentration values for each contaminant group measured at each survey site in the Chesapeake Bay are presented in Table 5. In caged oysters, most groups of contaminants were detected at multiple sites, though at various concentrations. However, the cyclohexane based pesticides (HCHs) were only found at one site in the Severn River, and none of the endosulfan pesticides were detected in the oysters. Results indicated that, relative to other riverine sites, the highest concentrations of Total Chlordanes, Total Chlorobenzenes, Total DDTs, Total Dieldrins, Mirex, Total PAHs and Total PCBs were detected in the Patapsco River. Additionally, six of the ten compound groups analyzed (Total Chlordanes, Total Chlorobenzenes, Total DDTs, Total Dieldrins, Total PAHs and Total PCBs) have higher concentrations at all four Patapsco River sites compared to the historic MWP data's 85th percentile. The Patapsco-4 site in particular stood out due to concentrations that were over twice the concentration of the next highest site for Total Chlordanes and Total DDTs. The Patapsco-4 site had the highest concentration for seven of the nine detected compound groups. This site is located in the vicinity of Masonville Cove which has poor water circulation.

**Table 5. Total contaminant class concentrations in caged and wild oyster tissue samples (ng/dry g). Based on historic sampling procedures, a subset of compounds was summed for PAHs and PCBs for comparison with national MWP 50th and 85th percentiles.**

| Site Name | Total Butyltins (n=4) | Total Chlordanes (n=7) | Total Chloro-benzenes (n=5) | Total DDTs (n=6) | Total Dieldrins (n=3) | Total Endo-sulfans (n=3) | Total HCHs (n=4) | Mirex (n=1) | Total PAHs (n=64) | Total PAHs subset (n=58) | Total PCBs (n=83) | Total PCBs subset (n=39) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Choptank-1 | 1.74 | 7.09 | 1.87 | 15.03 | 1.10 | 0.00 | 0.00 | 0.00 | 106.61 | 101.22 | 97.26 | 69.35 |
| Choptank-2 | 1.50 | 7.62 | 1.84 | 12.78 | 1.68 | 0.00 | 0.00 | 2.51 | 83.49 | 76.79 | 88.91 | 65.14 |
| Choptank-3 | 3.19 | 10.69 | 0.00 | 26.67 | 2.14 | 0.00 | 0.00 | 0.00 | 104.46 | 99.54 | 99.71 | 82.52 |
| Choptank-4 | 4.89 | 4.79 | 2.80 | 7.17 | 1.71 | 0.00 | 0.00 | 0.00 | 744.10 | 730.56 | 49.93 | 40.43 |
| Patapsco-1 | 18.63 | 54.46 | 1.98 | 34.74 | 17.25 | 0.00 | 0.00 | 0.00 | 1526.10 | 1494.61 | 467.54 | 332.87 |
| Patapsco-2 | 17.50 | 56.35 | 2.90 | 21.68 | 17.18 | 0.00 | 0.00 | 0.00 | 1307.70 | 1220.76 | 691.45 | 505.09 |
| Patapsco-3 | 18.51 | 85.48 | 4.66 | 58.14 | 25.59 | 0.00 | 0.00 | 2.48 | 1253.33 | 1162.83 | 703.87 | 562.41 |
| Patapsco-4 | 16.02 | **214.14** | **6.45** | **188.54** | **39.58** | 0.00 | 0.00 | **2.56** | **3249.01** | **3169.05** | **978.80** | **769.92** |
| Rhode-1 | 89.91 | 10.48 | 1.40 | 15.40 | 2.89 | 0.00 | 0.00 | 0.00 | 121.53 | 114.96 | 109.15 | 94.48 |
| Rhode-2 | 21.79 | 8.29 | 0.00 | 18.61 | 1.96 | 0.00 | 0.00 | 0.00 | 107.90 | 103.58 | 138.35 | 117.60 |
| Rhode-3 | 18.93 | 7.73 | 2.11 | 16.33 | 2.09 | 0.00 | 0.00 | 0.00 | 92.78 | 88.60 | 158.77 | 135.72 |
| Rhode-4 | 6.36 | 6.97 | 0.00 | 14.34 | 0.00 | 0.00 | 0.00 | 1.32 | 99.81 | 96.52 | 102.91 | 86.11 |
| Severn-1 | 46.13 | 15.74 | 0.00 | 22.06 | 6.26 | 0.00 | 0.00 | 0.00 | 386.40 | 379.95 | 149.06 | 119.97 |
| Severn-2 | **327.23** | 29.77 | 1.49 | 31.78 | 8.52 | 0.00 | 0.00 | 0.00 | 694.61 | 681.79 | 286.23 | 236.96 |
| Severn-3 | 112.36 | 44.88 | 4.75 | 41.90 | 9.04 | 0.00 | **0.48** | 0.00 | 1695.59 | 1681.01 | 503.45 | 397.93 |
| CBBH | 78.62 | 7.83 | 2.12 | 7.56 | 2.26 | 0.00 | 0.00 | 0.00 | 47.58 | 47.58 | 50.66 | 41.94 |
| CBBO | 66.07 | 9.84 | 2.14 | 14.72 | 2.31 | 0.00 | 0.00 | 0.00 | **313.55** | **310.05** | 131.09 | 94.76 |
| CBCP | 0.00 | 4.94 | 1.88 | 5.07 | 1.24 | 0.00 | 0.00 | 0.00 | 35.64 | 35.64 | 30.38 | 24.07 |
| CBMP | 96.30 | **11.09** | **4.68** | **16.22** | **3.03** | 0.00 | 0.00 | 0.00 | 244.54 | 244.54 | **143.68** | **95.16** |
| CBSB | **102.78** | 5.77 | 1.55 | 6.66 | 1.32 | 0.00 | 0.00 | 0.00 | 59.51 | 59.51 | 37.38 | 28.13 |

Notes: Bold, highest concentration in each contaminant group for caged and wild oysters seperately; DDT, dichlorodiphenyltrichloroethane; HCH, hexachlorocyclohexane; PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl

The Severn River had the second highest overall caged oyster tissue concentrations with all three of its sites being over the historic MWP data's 85th percentile for Total Butytins, Total DDTs, Total Dieldrins, and Total PCBs. It also had two of the highest site concentrations (for Total Butytins and Total HCHs), although for two different sites (Severn-2 and Severn-3 respectively). The two highest Total Butyltins concentrations in this study were detected at sites Severn-2 and Severn-3, which were respectively located near the mouths of the Back Creek and Spa Creek of the Severn River. Additionally, Severn-3 site was the only location where Total HCHs was detected in oyster tissue.

Among the historic MWP sites where wild oysters were collected, all contaminant groups analyzed were detected except for Total Endosulfans, Total HCHs, and Mirex. The wild oyster tissue collected at the historic MWP site CBMP, located near Mountain Point in the bay, had five of the seven highest site concentrations for wild oyster tissue (Total Chlordanes, Total Chlorobenzenes, Total DDTs, Total Dieldrins, and Total PCBs). The highest Total Butyltins concentration in wild oysters was recorded at the CBSB site near Simmons Bar, while the CBBO site, in the vicinity of the Seven Foot Knoll at the mouth of the Patapsco River, had the highest Total PAHs concentration (Table 5). A more detailed analysis of each contaminant group including land-use analyses, comparisons to guidelines and trend analyses is presented below.

### 3.1 TOTAL BUTYLTINS

Total Butyltins in the Chesapeake Bay oyster tissues varied from 1.50 (ng Sn/g dry g) to a maximum concentration of 327.23 ng Sn/dry g found in caged oysters at Severn-2 (Table 5). This value was more than double any other value detected in this study. The mean value of Total Butyltins in caged oysters was 46.98 ± 21.71 ng Sn/dry g (mean ± SE) (Appendix 4). Total Butyltins in the Chesapeake Bay wild oyster tissue had a maximum value of 102.78 ng Sn/dry g found at site CBSB. The mean value of Total Butyltins in wild oyster tissue was 68.75 ± 18.37 ng Sn/dry g (mean ± SE).

The results indicated that tributyltin, the primary active compound, followed by the degradation by-product dibutyltin, were the dominant organo-tin contaminants found in oyster tissue in the Chesapeake Bay (Figure 4). Tributyltin was detected at 18 of the 20 sites and dibutyltin at 17. Monobutyltin was detected at eight sites and tetrabutyltin was not detected (Appendix 6).

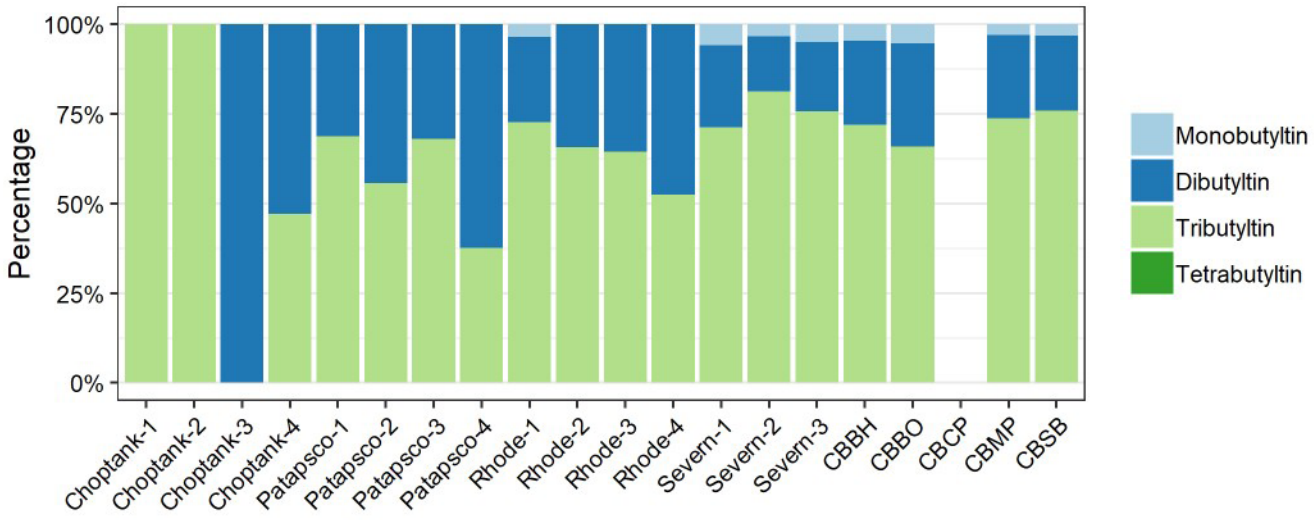


**Figure 4. Percent composition of individual butyltin contaminants in Total Butyltins per site in oyster tissue.**

Comparisons with Other Data and Guidelines. The national MWP 50th and 85th percentiles for Total Butyltins data are currently calculated as 0.00 ng Sn/dry g and 40.04 ng Sn/dry g respectively (Table 3). Among the caged oysters, all sites in the Severn River and Rhode-1 exceeded the 85th percentile (Figure 5). All other river-based sites exceeded the 50th percentile. All historic MWP sites, except for CBCP located in the mainstem of the Choptank River, exceeded the 85th percentile threshold. Tributyltin was prevalent in the bay, however, concentrations did not exceed either the EPA's subsistence or recreational fishing Screening Values (Appendix 5).

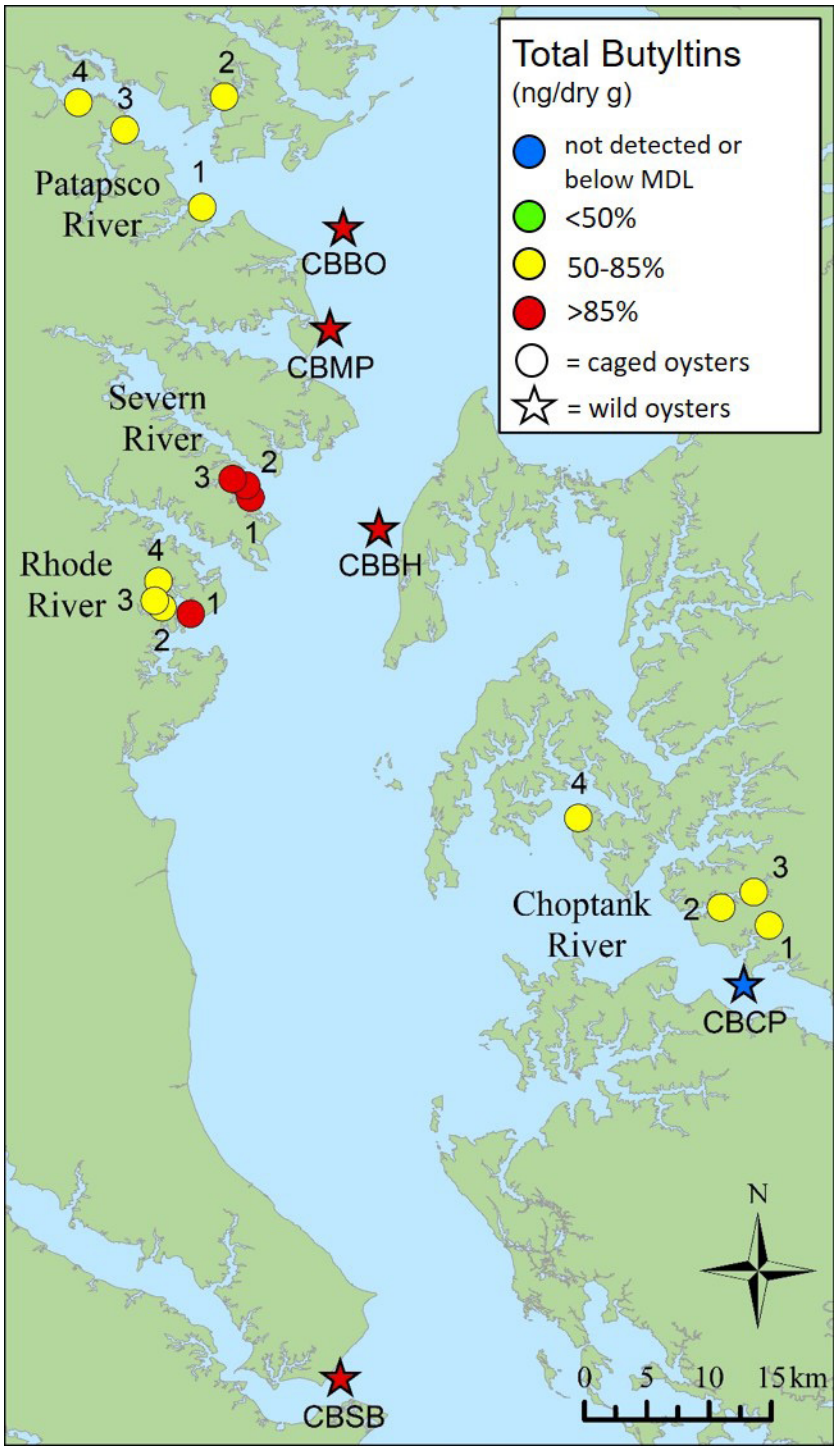


**Figure 5. Total Butyltin oyster tissue concentrations in comparison to the national MWP 50th and 85th percentiles (0.00 ng Sn/dry g and 40.04 ng Sn/dry g respectively).**

Land-use Assessment. There was a significant difference between river concentrations (p-value = 0.01) for Total Butyltins in caged oysters (Figure 6). The Severn and Rhode Rivers were shown to have significantly higher concentrations of Total Butyltins than the Choptank River (Figure 6). In general, there appeared to be higher concentrations of Total Butyltins in samples closer to the bay mainstem than samples within the tributaries.

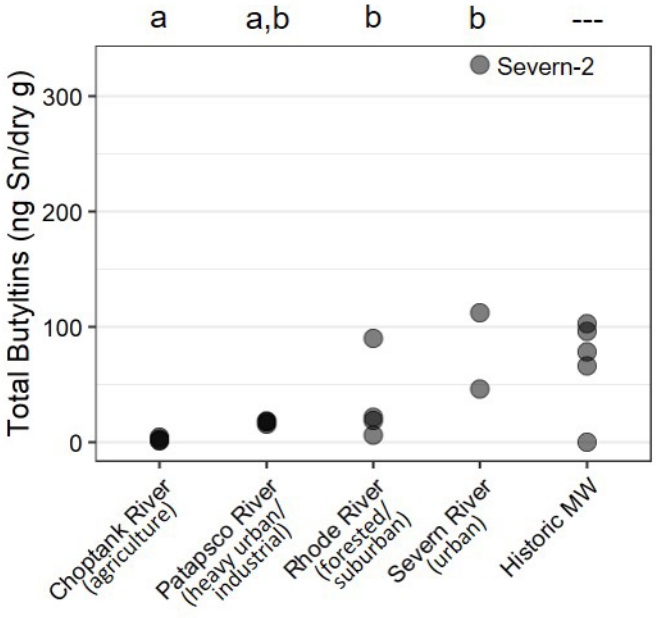


**Figure 6. Total Butyltins concentrations in caged oyster tissue by river and in wild oyster tissue at the historic MW sites. Letters represent statistical differences between rivers.**

Temporal Trend Analysis. The temporal trend assessment was based on the historical MWP monitoring sites only. Pronounced temporal fluctuations for Total Butyltins were recorded at sites located near the mouth of major rivers where maximum concentrations were found. Temporal trends varied greatly at each long-term monitoring site (Figure 7A, particularly at the CBBH and CBBO sites). However, the moving average results showed an overall decreasing temporal trend for butyltin compounds in the Chesapeake Bay during the last 30 years (Figure 7B).

Summary of butyltins in oyster tissue. Despite the application ban of butyltin-based antifouling paints on non-aluminum vessels smaller than 25 meters in length, these results show that butyltin compounds are persisting in the Chesapeake Bay estuarine environment. The high concentrations of butyltin in the Severn River and at four of the historic MWP sites could be attributed to the anthropogenic activities of the maritime shipping industry of the Baltimore Harbor with its presence of large vessels, intensive recreational boating activities, and presence of the network of marinas and a nearby naval base. Additionally, the Severn River is a historic site for sailing boat construction as well as the host site for major national and international recreational sailing championship events. High butyltin concentrations at historical MWP sites, which are typically in deeper mainstem waters, could be an indication of the continuing use of tributyltin on larger vessels and the traffic of ships through the Chesapeake Bay. The presence of a majority percentage of tributyltin compared to di- or mono- butyltin further suggests the presence of fresh sources in these locations. Additionally, the reported half-life of tributyltin in estuarine waters ranges from days to weeks (Omae, 2005), but in bottom sediment where TBT is chemically sorbed to sediment particles, the half-life can extend to years and into decades in anaerobic sediment conditions (Matthiessen, 2013).

# Results

Despite the fact that Total Butyltin concentrations were above the national 85th percentile value at many sites, it is worthwhile to note that none of these concentrations exceeded EPA guidelines for subsistence fishers and concentrations (Appendix 5). Presence of fresh TBT has the potential to cause serious ecosystem health issues in the Bay. The site-specific temporal variations observed may have been influenced by local source input and weather conditions. However, it is equally relevant to highlight the general decreasing trend of total butyltins in the bay over the MWP monitoring years. This decreasing trend is an indication of a positive effect from regulation since the first year the MWP tested for butyltins. Of note, the first year of MWP monitoring in 1989 was the same year that butyltin use was banned on ships under 25 meters.

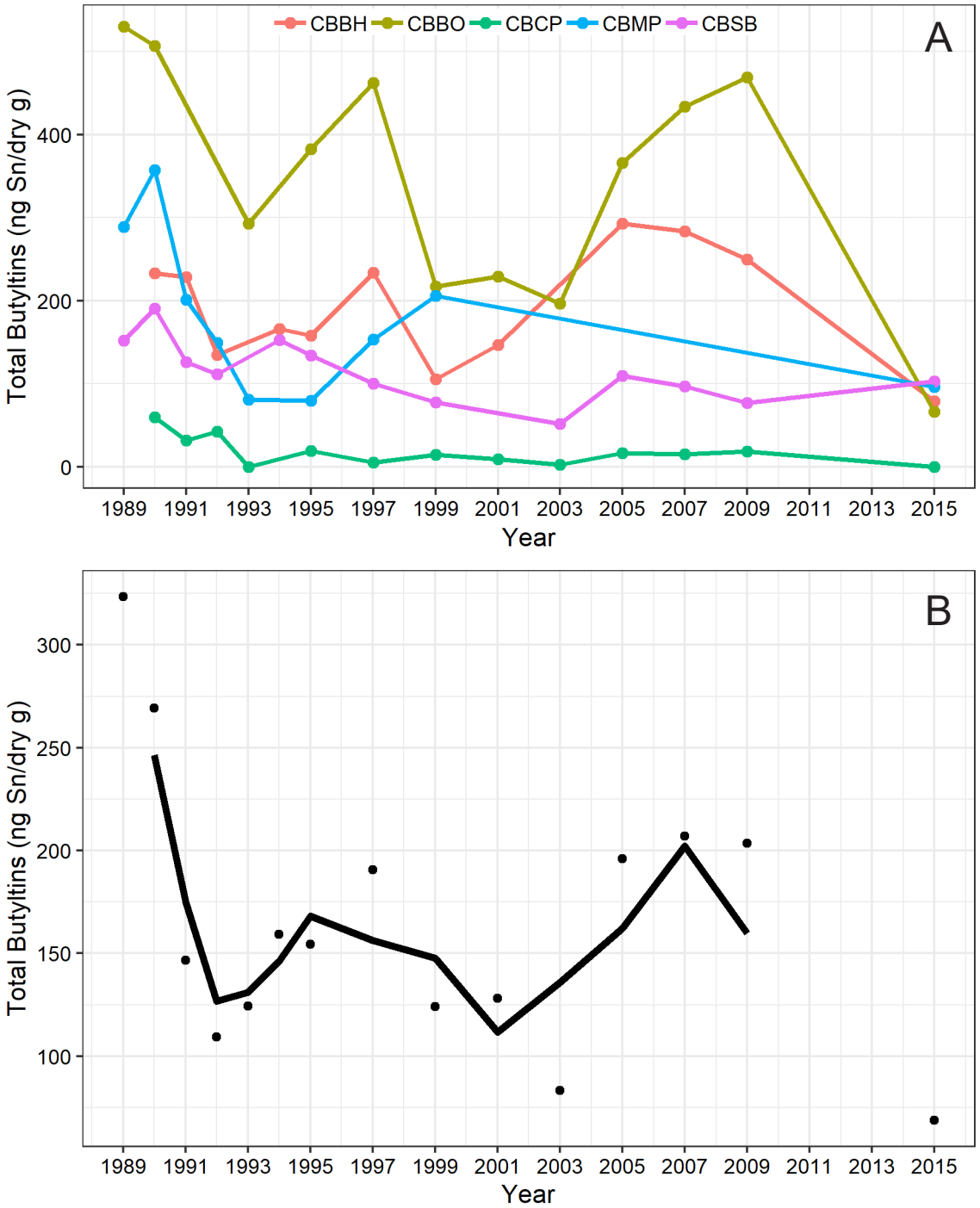


**Figure 7. A: Total Butyltin concentrations in wild oyster tissue by year at the five historic MWP sites. B: Moving average showing the overall temporal trends of Total Butyltin in the Chesapeake Bay study area.**

### 3.2 TOTAL CHLORDANES

Chlordanes were found at each survey site in tissue including wild and caged oyster tissue; however, the Total Chlordane concentrations varied broadly across the study area (Table 5). The maximum concentration for Total Chlordanes in caged oyster tissue was 214.14 ng/dry g found at Patapsco-4 site (Table 5) located in the Masonville Cove, a poorly flushed waterbody within the bay. This value was more than double any other value detected in this study. The mean value (± SE) of Total Chlordanes in caged oys-

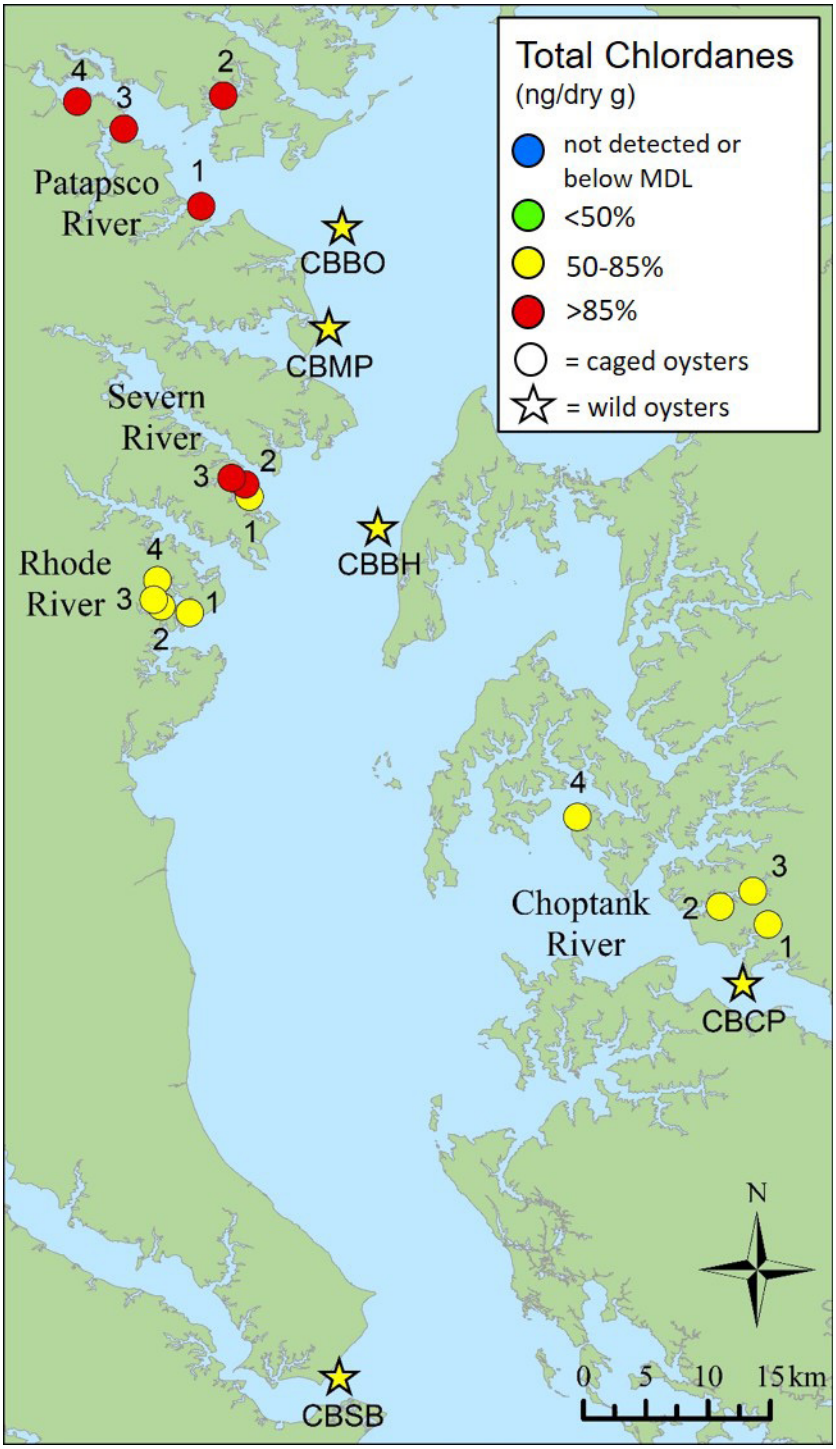


**Figure 8. Total Chlordane oyster tissue concentrations in comparison to the national MWP 50th and 85th percentiles (4.03 ng/dry g and 17.18 ng/dry g respectively).**

ter tissue was 37.60 ± 14.10 ng/dry g (Appendix 4). Among the wild oyster sites, the maximum value of 11.09 ng/dry g Total Chlordanes was found at CBMP site located on the Mountain Point oyster bar in the mainstem of the bay. The mean value of Total Chlordanes for wild oysters was 7.89 ± 1.17 ng/dry g (mean ± SE). Total Chlordane concentrations were dominated by the presence of cis- and trans- nonachlor and alpha- and gamma- chlordane. Heptachlor was not detected (Appendix 6).

Comparisons with Other Data and Guidelines. The national MWP 50th and 85th percentile values for Total Chlordanes were calculated as 4.03 ng/dry g and 17.18 ng/dry g respectively (Table 3). Using these values, all of the caged and wild oyster sites exceeded the national 50th percentile (Figure 8). All sites in the Patapsco River, and sites 2 and 3 in the Severn River, located in the Back Creek and Spa Creek respectively, exceeded the 85th percentile. Only oysters from the Patapsco-4 site had tissue concentration that exceeded the EPA SVs for Total Chlordanes (Appendix 5). Heptachlor epoxide concentrations exceeded EPA SVs for subsistence fishers at Patapsco-3 and Patapsco-4.

Land-use Analysis. There was a significant difference between river concentrations (p-value = 0.01). Caged oyster sites in the Patapsco River had significantly higher concentrations of Total Chlordanes compared to sites in the Rhode or Choptank Rivers (Figure 9). Caged oysters in the Rhode, Choptank and Severn Rivers did not have significantly different concentrations of Total Chlordanes from each other (Figure 9).

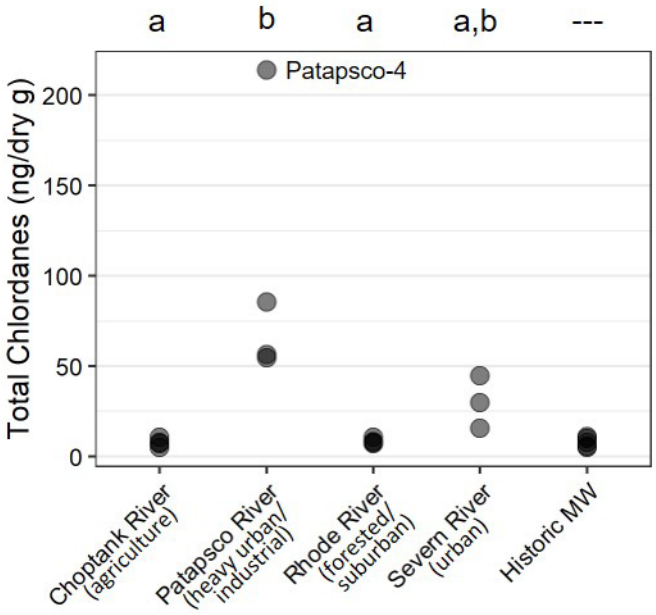


**Figure 9. Total Chlordane concentrations in caged oyster tissue by river and in wild oyster tissue at the historic MW sites. Letters represent statistical differences between rivers.**

Trend Analysis. The analytical results showed a consistent temporal decreasing trend at all of the five long-term monitoring sites (Figure 10A). The moving average analysis statistically confirmed this observation bay-wide of a pronounced decrease in Total Chlordanes concentrations between 1986 and 2000 after which the concentration appeared to level off (Figure 10A and B).

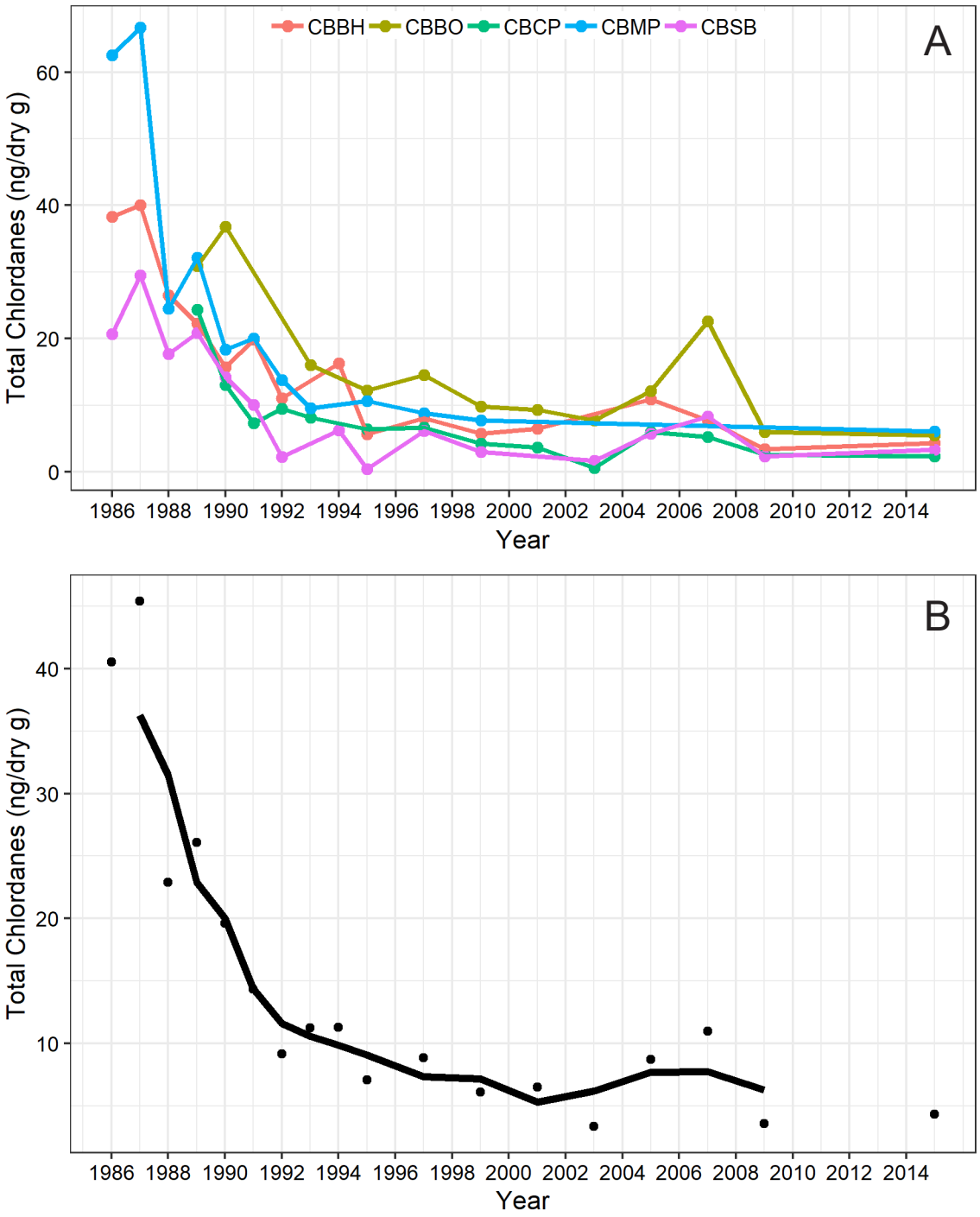


**Figure 10. A: Total Chlordane concentrations in wild oyster tissue by year at historic MWP sites. B: Moving average showing the overall temporal trends of Total Chlordane in in the Chesapeake Bay study area.**

Summary of chlordanes in oyster tissue. Total Chlordane concentrations have been decreasing in the Chesapeake Bay over time since the beginning of MWP site sampling which corresponds closely with the total ban of chlordane in 1988. The higher concentrations in the Patapsco River are probably related to the use of chlordane for residential termite control until 1988, especially since the highest concentration, and the only one above EPA SVs, is located at Patapsco-4 which is the site closest to the city of Baltimore. Additionally, the fact that that two sites that are close to the city of Annapolis in the Severn River have concentrations above the national 85th percentile, supports a potential link between chlordane concentrations and these urban environments.

### 3.3 TOTAL CHLOROBENZENES

Chlorobenzenes were detected in oyster tissue from all survey sites except in caged oysters at Severn-1, Rhodes-4, and Choptank-3 (Table 5). Among the caged oysters, Total Chlorobenzene concentration varied from undetected to a maximum value of 6.45 ng/dry g found at Patapsco-4. The next two highest Total Chlorobenzene concentrations were found at Severn-3 (4.75 ng/dry g) in the Spa Creek and Patapsco-3 (4.66 ng/dry g) in Curtis Bay. The mean value of Total Chlorobenzenes in caged oysters was 2.15 ± 0.50 ng/dry g (mean ± SE) (Appendix 4). Total Chlorobenzenes in the Chesapeake Bay wild oyster tissue had

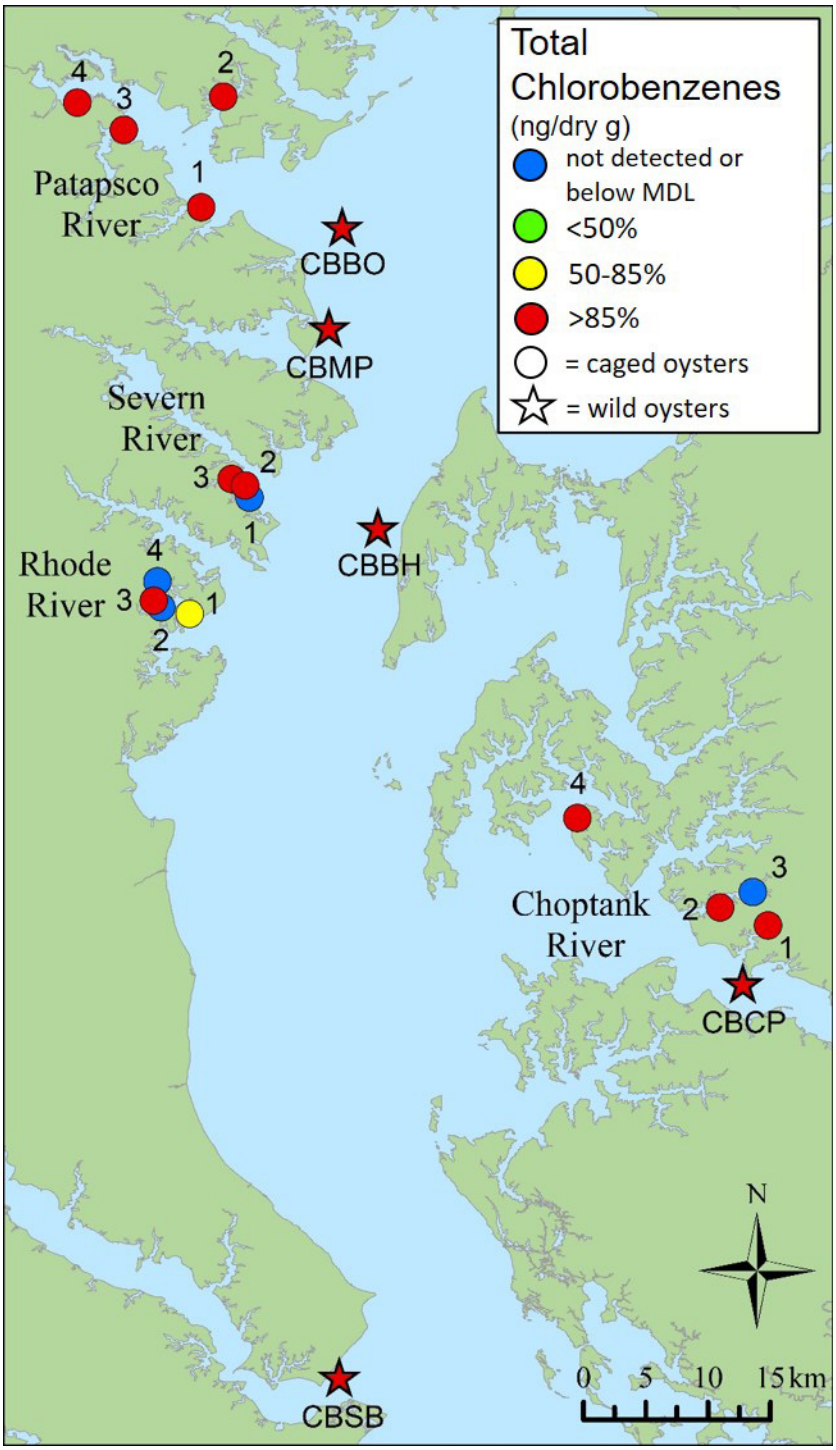


**Figure 11. Total Chlorobenzene oyster tissue concentrations in comparison to the national MWP 50th and 85th percentiles 0.33 ng/dry g and 1.29 ng/dry g respectively.**

a maximum value of 4.68 ng/dry g found at site CBMP. The mean value of Total Chlorobenzenes in wild oysters was 2.47 ± 0.56 ng/dry g (mean ± SE). Most sites only had one compound detected, either pentachloroanisole or 1,2,3,4-tetrachlorobenzene. Severn-2 was the only site where hexachlorobenzene was detected and neither 1,2,4,5-tetrachlorobenzene or pentachlorobenzene were detected. Pentachloroanisole was mainly detected in the Patapsco River, Choptank River and historic MW sites, while 1,2,3,4-tetrachlorobenzene was predominant in the Rhode River (Appendix 6).

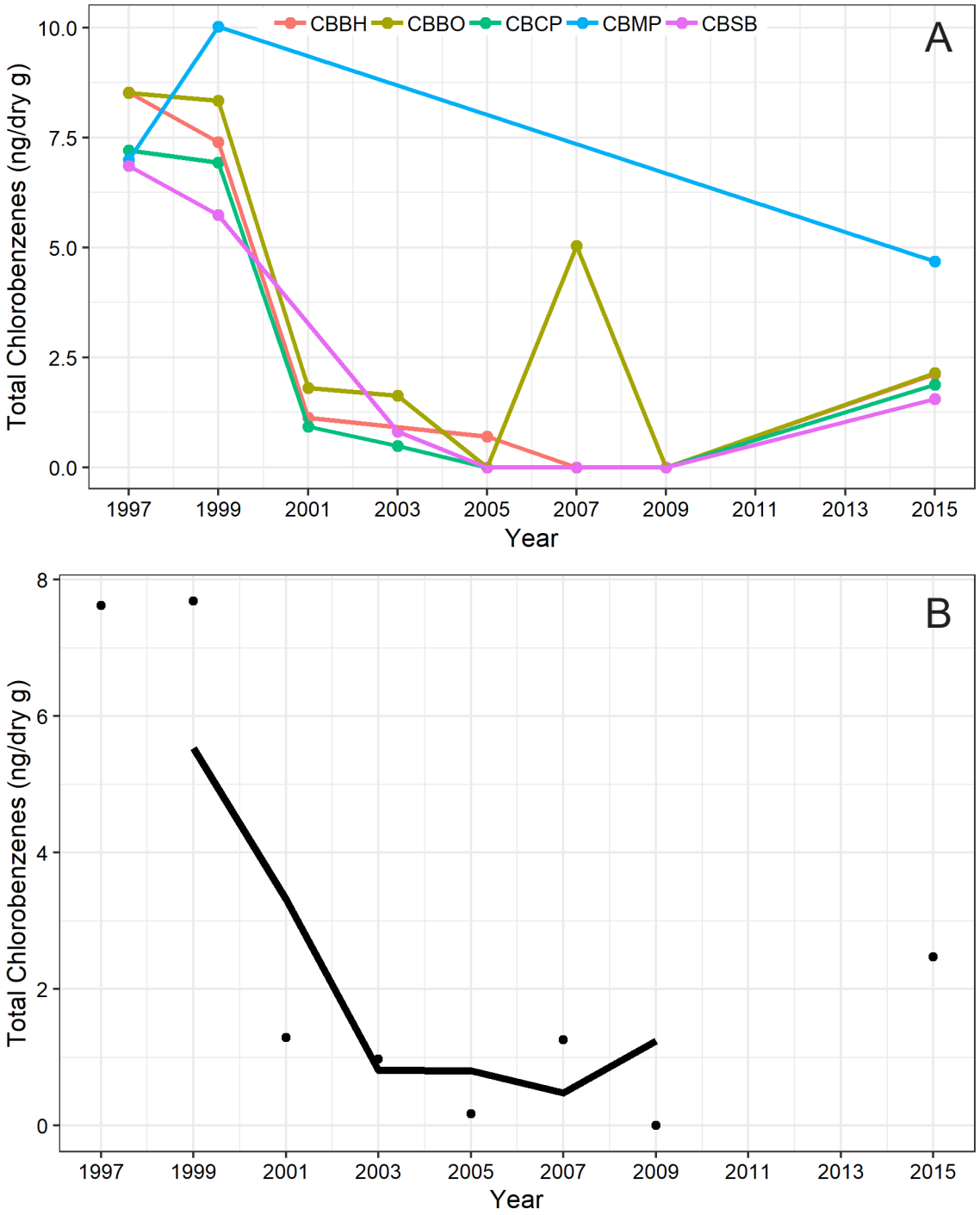


**Figure 12. A: Total Chlorobenzene concentrations in wild oyster tissue by year at historic MWP sites. B: Moving average showing the overall temporal trends of Total Chlorobenzene in in the Chesapeake Bay study area.**

Comparisons with Other Data and Guidelines. The national MWP 50th and 85th percentiles for Total Chlorobenzenes data are currently calculated as 0.33 ng/dry g and 1.29 ng/dry g respectively. All sites in the Patapsco River, sites 1 and 4 in the Choptank River, sites 2 and 3 in the Severn River, and Rhode-3 all exceeded the 85th percentile (Figure 11). Additionally, Rhode-1 exceeded the 50th percentile. All historic MWP sites exceeded the 85th percentile. Hexachlorobenzene, which was only detected at Severn-2, did not exceed the EPA SVs.

Land-use Analysis. There was no significant difference between river concentrations (p-value = 0.09).

Trend Analysis. Although site-specific temporal variations can be observed for Total Chlorobenzene (Figure 12A), overall the compound has steadily decreased bay-wide until 2009 before a slight increase in concentration through 2015 (Figure 12B).

Summary of chlorobenzenes in oyster tissue. Since the use of chlorobenzenes are regulated, but not banned, some potential new sources of chlorobenzenes still exist and could account for the recent increase in the Chesapeake Bay.

### 3.4 TOTALS DDTs

Total DDTs in the Chesapeake Bay Rivers had a maximum concentration of 188.54 ng/dry g, which occurred at Patapsco-4 (Table 5). This value was more than double any other value detected in this study. The mean value of Total DDT in caged oyster tissue was 35.01 ± 11.48 ng/dry g (mean ± SE) (Appendix 4). Total DDTs in the Chesapeake Bay wild oyster tissue had a maximum value of 16.22 ng/dry g found at site CBMP located on the Mountain Point oyster bar. The mean value of Total DDTs in wild oyster tissue was 10.05 ± 2.26 ng/dry g (mean ± SE). Results indicated that in the Chesapeake Bay the parent DDT compounds are still present. Although all six forms of DDT were detected, Total DDT concentrations were dominated by the presence of the 4,4'-DDE isomer (Figure 13) (Appendix 6).

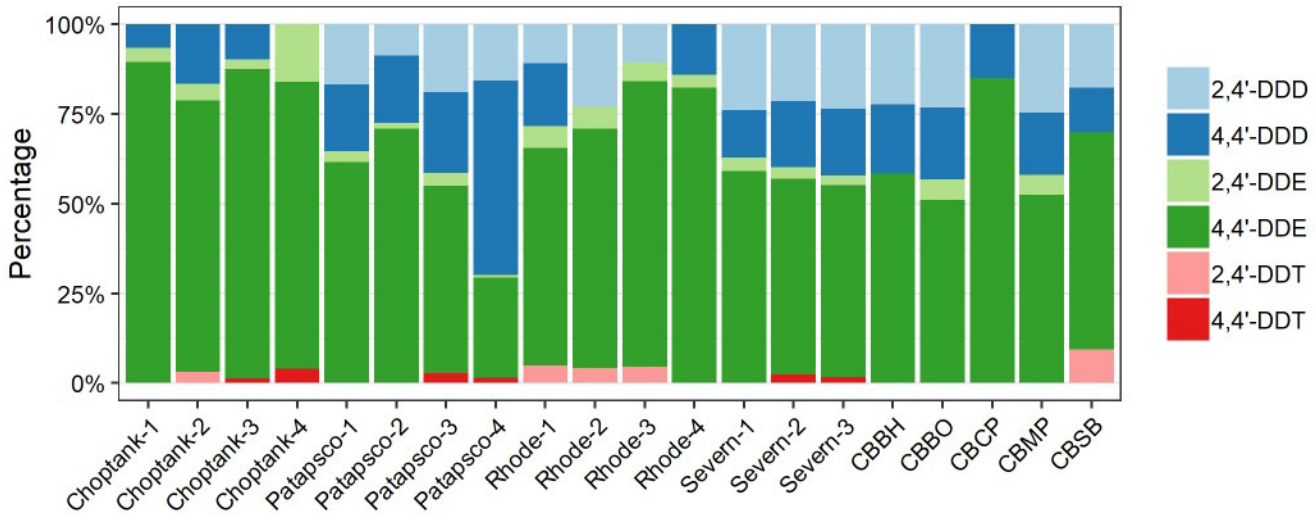


**Figure 13. Percent composition of individual DDT contaminants in Total DDTs per site in oyster tissue.**

Comparisons with Other Data and Guidelines. The national MWP 50th and 85th percentiles for Total DDTs are currently calculated as 6.84 ng/dry g and 20.26 ng/dry g respectively. All of the caged oyster sites exceeded the 50th percentile for Total DDTs (Figure 14). The 85th percentile value was exceeded by all the sites in the Patapsco and Severn Rivers, along with Choptank-3. DDTs were found at all historic MWP sites, but none of the wild oyster tissue had Total DDTs concentration that exceeded the national 85th percentile. However, the CBBH sample, on the Brick House oyster bar near the mouth of Severn River, as well as CBBO and CBMP, both of which are near the Patapsco River, exceeded the

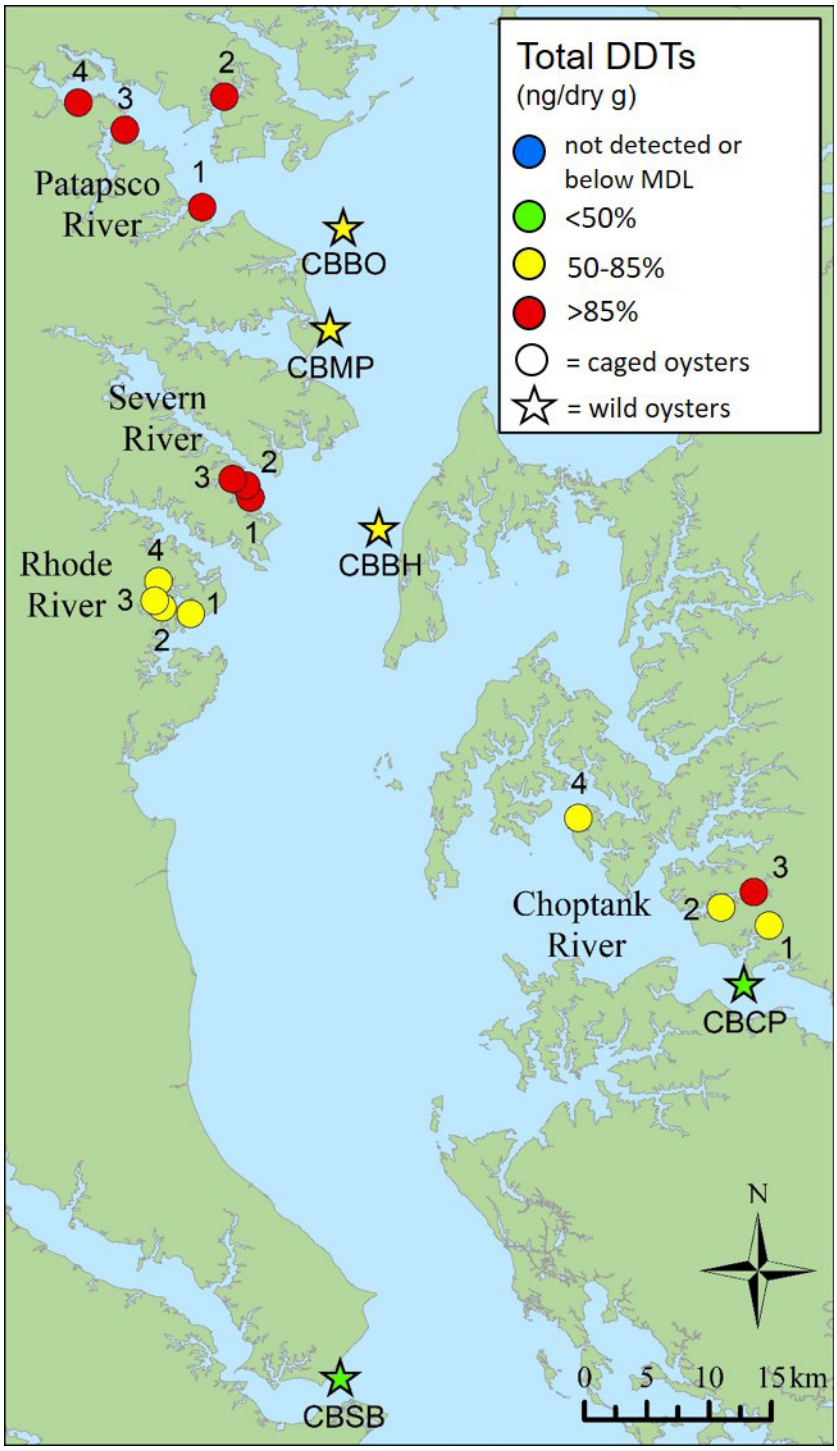


**Figure 14. Total DDT oyster tissue concentrations in comparison to the national MWP 50th and 85th percentiles (6.84 ng/dry g and 20.26 ng/dry g respectively).**

50th percentile. Total DDT concentrations did not exceed the FDA action level, however the Total DDT concentration at Patapsco-4 site located in the poorly flushed Masonville Cove exceeded the EPA SV for subsistence fishers (Appendix 5).

Land-use Analysis. There was a significant difference between river concentrations (p-value = 0.03) where the Patapsco and Severn Rivers had significantly higher concentrations of Total DDTs than the Choptank River, and the Patapsco River also had higher concentrations than the Rhode River (Figure 15).

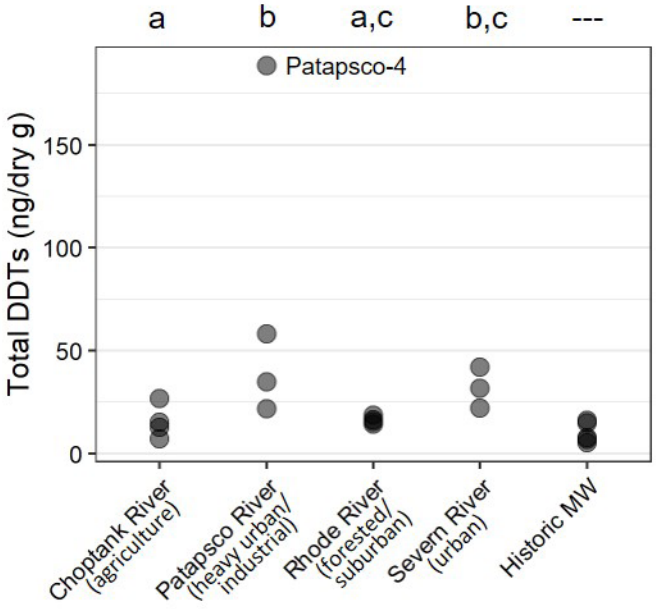


**Figure 15. Total DDT concentrations in caged oyster tissue by river and in wild oyster tissue at the historic MW sites. Letters represent statistical differences between rivers.**

Trend Analysis. The results indicated consistent decreasing site-specific and bay-wide temporal trends in the Chesapeake Bay as shown in the moving average analysis (Figures 16A and B).

Summary of DDTs in oyster tissue. Although DDT was banned for most uses in the US beginning in 1972, the results indicate that residues still persist in the environment, though at much lower concentrations than originally detected in 1986. The presence of p,p' DDT suggests that there are still some new sources entering the aquatic environment. Although the highest Total DDT tissue concentrations were found in sites associated with urban and industrial land-use (the Patapsco and Severn Rivers), p,p'-DDT was detected in all of the rivers. The moving average analysis indicated that Total DDT has consistently decreased in the Chesapeake Bay study area since 1986, certainly as the result of regulation that banned the application of the compound in the 1970's (Figure 16A and B).

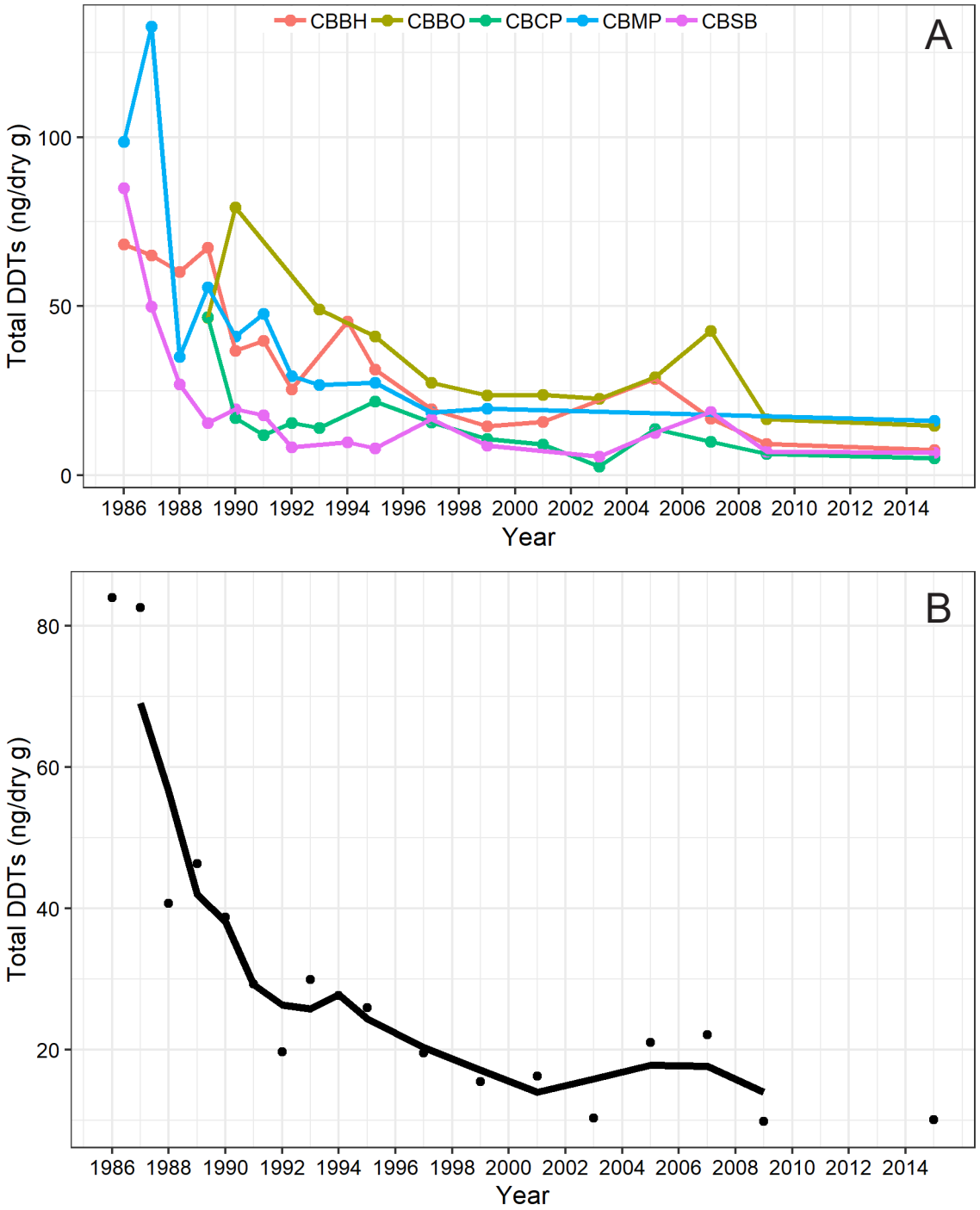


**Figure 16. A: Total DDT concentrations in wild oyster tissue by year at historic MWP sites. B: Moving average showing the overall temporal trends of Total DDTS in in the Chesapeake Bay study area.**

### 3.5 TOTAL DIELDRINS

Total Dieldrins in the Chesapeake Bay caged oyster tissue had a maximum value of 39.58 ng/dry g found at Patapsco-4 (Table 5). The mean concentration of dieldrin related compounds in caged oyster tissue was 9.13 ± 2.92 ng/dry g (mean ± SE) (Appendix 4). Total Dieldrins in the Chesapeake Bay wild oyster tissue had a maximum value of 3.03 ng/dry g found at CBMP. The mean value of Total Dieldrins in wild oyster tissue was 2.03 ± 0.34 ng/dry g (mean ± SE). Total Dieldrin tissue concentrations were dominated by the presence of dieldrin. Aldrin was only detected at Patapsco-1, 2 and 4, and Severn-1. Endrin was only detected at Patapsco-2 and 3 (Appendix 6).

Comparisons with Other Data and Guidelines. The national MWP 50th and 85th percentiles for Total Dieldrin data are currently calculated as 0.94 ng/dry g and 3.30 ng/dry g respectively. All caged oyster sites exceeded the 50th percentile except for Rhode-4. Additionally, all the sites in both the Severn and Patapsco Rivers exceeded the 85th percentile (Figure 17). All wild oyster tissue concentrations exceeded the 50th percentile but none exceeded the 85th. Aldrin and dieldrin concentrations did not exceed FDA guidelines; however, many sites exceeded EPA SVs (Appendix 5). The tissue concentration of dieldrin at all the sites in both the Severn and Patapsco Rivers and Rhode-1 exceeded the EPA's SV for subsistence fishers. Patapsco-3 and 4 even exceeded the SV for recreational fishers at 2.5 ng/g wet weight.

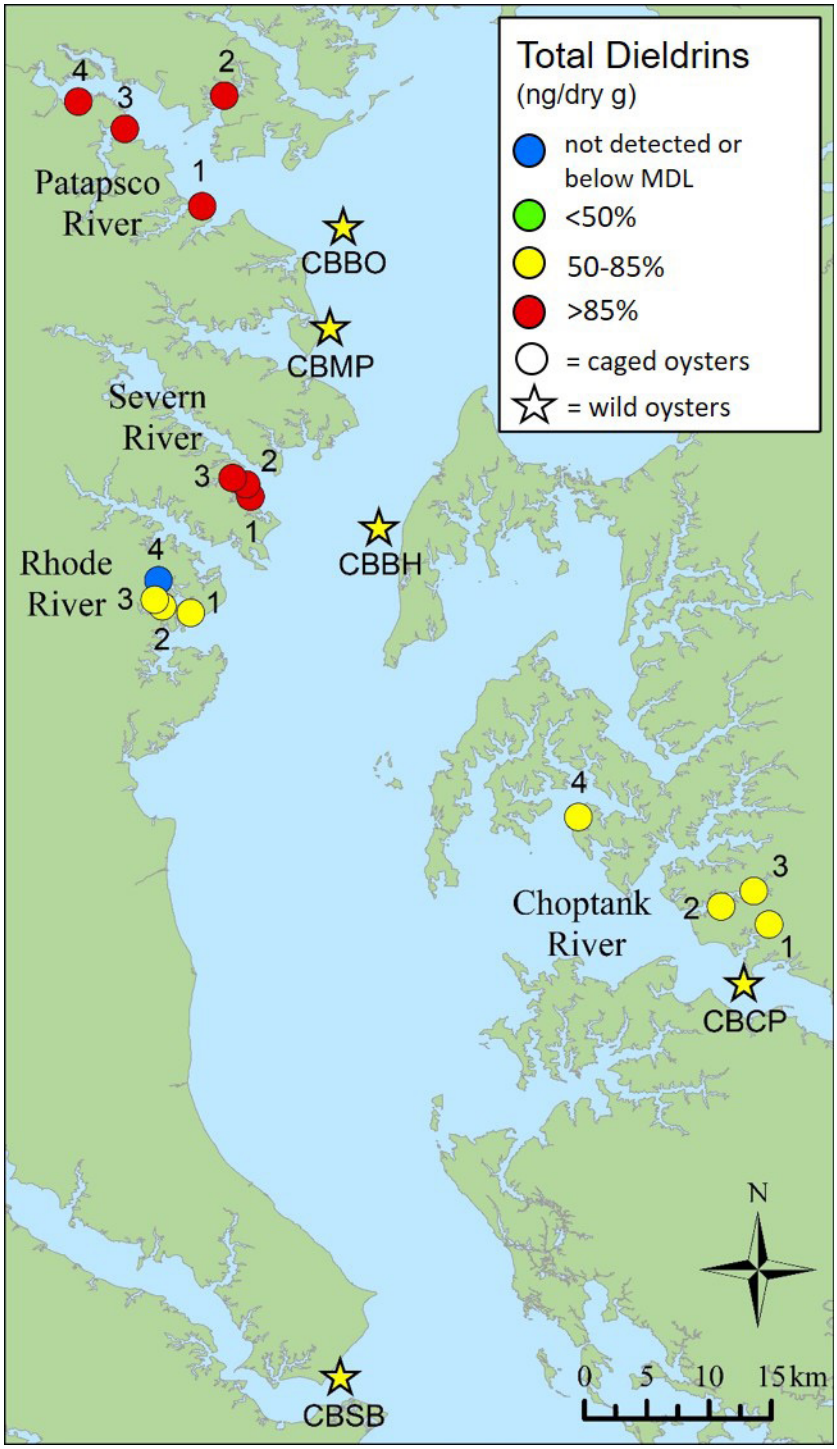


**Figure 17. Total Dieldrins oyster tissue concentrations in comparison to the national MWP 50th and 85th percentiles (0.94 ng/dry g and 3.30 ng/dry g respectively).**

The aldrin concentrations at Patapsco sites 1, 2 and 3 exceeded the EPA SV for subsistence fishers (Appendix 5).

Land-use Analysis. There was a significant difference between river concentrations (p-value = 0.01) where the Patapsco River had significantly higher concentrations of Total Dieldrins than the Rhode or Choptank Rivers (Figure 18).

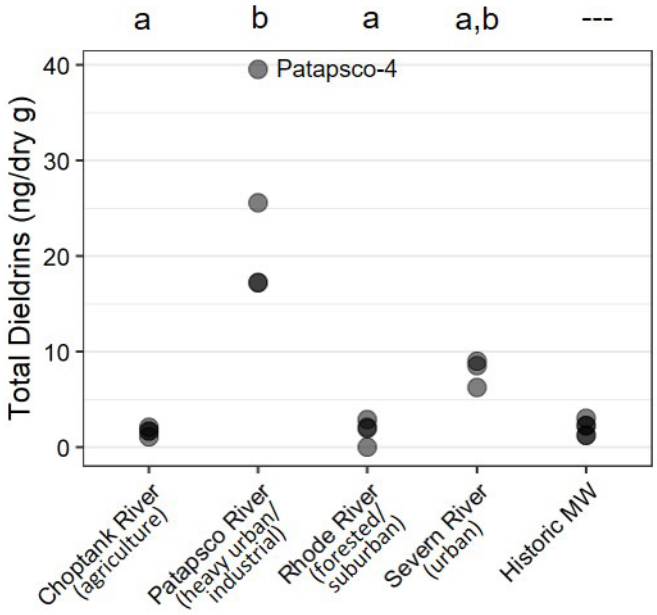


**Figure 18. Total Dieldrins concentrations in caged oyster tissue by river and in wild oyster tissue at the historic MW sites. Letters represent statistical differences between rivers.**

Trend Analysis. Total Dieldrin compound has similar temporal trend pattern as other chlorinated man-made pesticides like DDT. Trend analysis showed a consistent decreasing concentration of the chemicals in the Chesapeake Bay (Figure 19A and B).

Summary of dieldrins in oyster tissue. In 1974 the EPA banned all uses of diedrin and aldrin, except to control termites, and in 1987 all uses were banned. However, the data shows that dieldrins are persisting in the Chesapeake Bay estuarine environment. Dieldrins in water break down very slowly and they can bioaccumulate in animal fat tissues. Similar to chlordanes, the higher concentrations of dieldrin in the heavy urban environment of the Patapsco River could be the result of extensive termite control around the city of Baltimore. The predominance of dieldrin in the samples can be explained by the degradation of aldrin to dieldrin in the environment by sunlight and bacteria. Additionally, aldrin rapidly changes to dieldrin in plants and animals (ATSDR, 2002a). In the Chesapeake Bay environment, Total Dieldrin has substantially decreased over the years, likely as a result of the regulations that banned the chlorinated pesticides since the 1970's. However, the continuous detection of these chemicals in the environment can be liked to their chemical behavior and slow biodegradation characteristics.

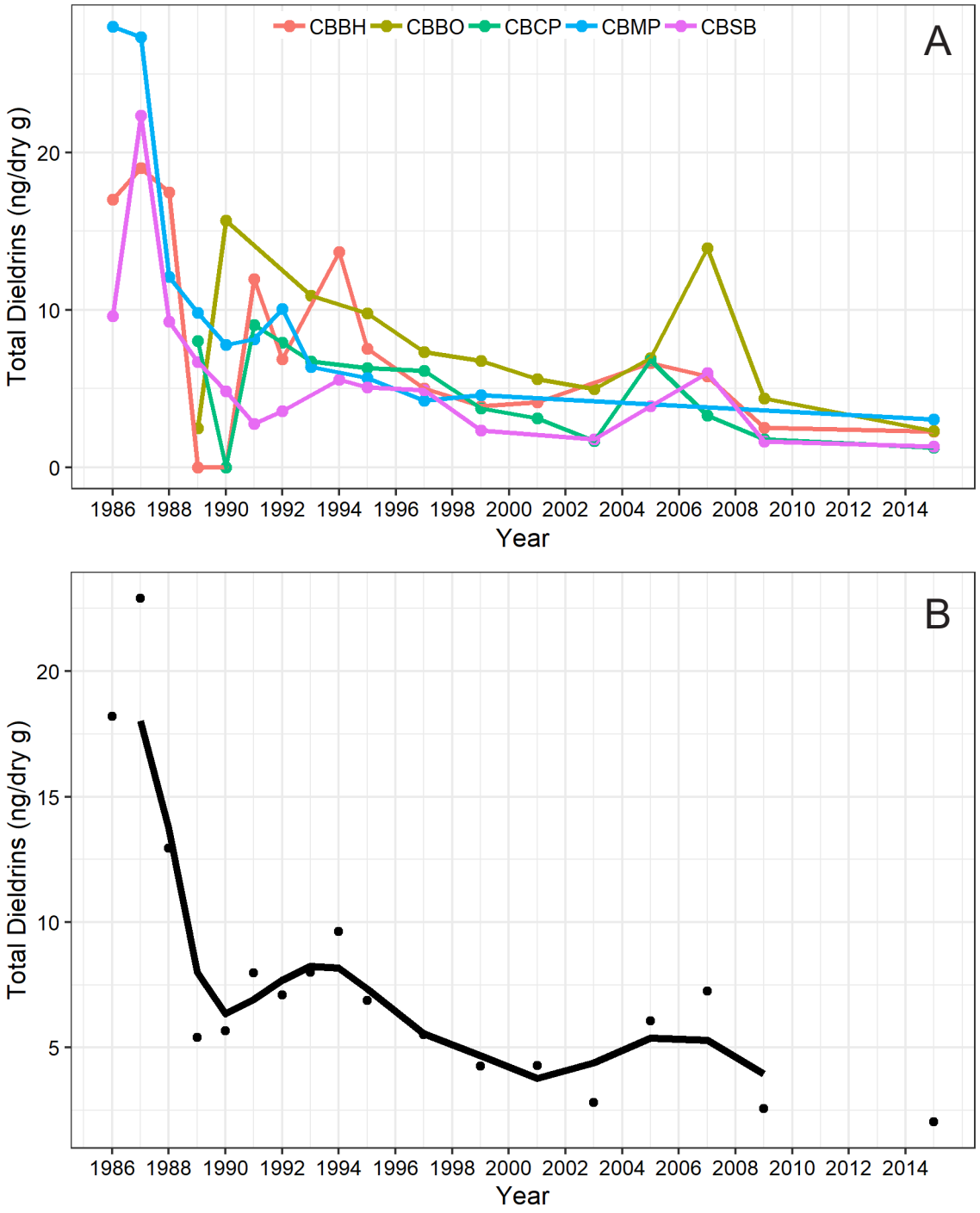


**Figure 19. A: Total Dieldrin concentrations in wild oyster tissue by year at historic MWP sites. B: Moving average showing the overall temporal trends of Total Dieldrin in in the Chesapeake Bay study area.**

### 3.6 TOTAL ENDOSULFANS

Endosulfans were not detected in either the caged or wild oyster tissue during the 2015 survey (Table 5).

Trend Analysis. No temporal trend was observed at any of the five long-term monitoring sites for Total Endosulfans concentration in oyster tissue over time in the Chesapeake Bay.

Summary of endosulfans in tissue. The trend analysis showed historic detection of endosulfans in oysters from the Chesapeake Bay (Figure 20). However, endosulfans contaminant were not detected in either the caged or wild oyster sites during the 2015 survey.

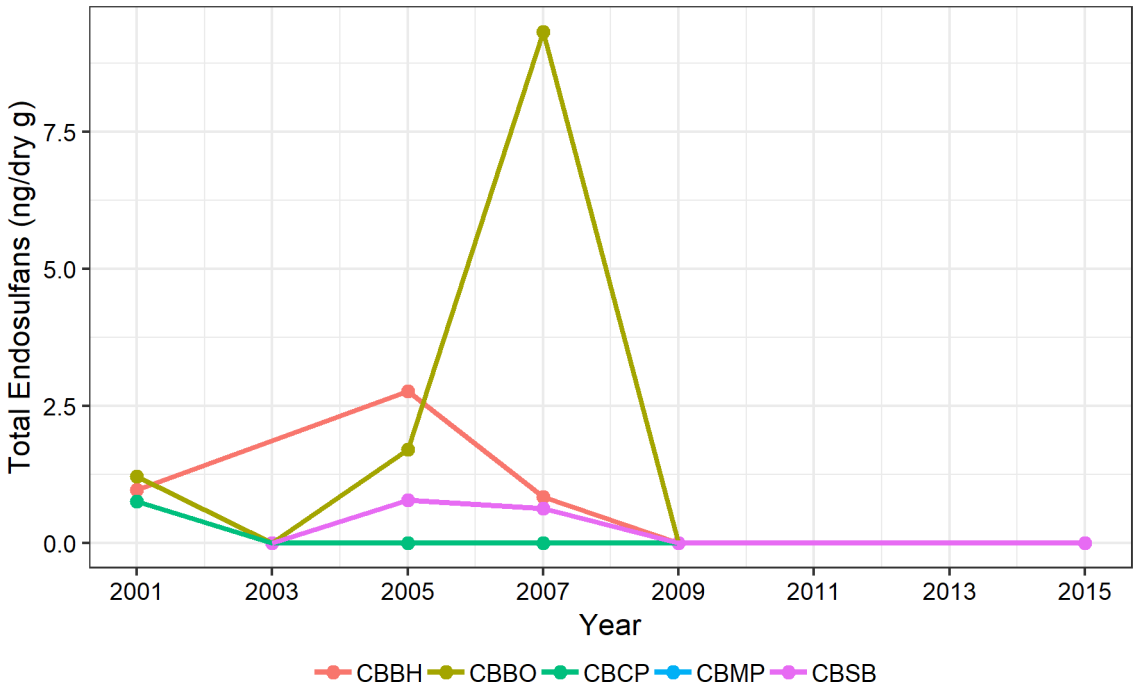


**Figure 20. Total Endosulfans concentrations in wild oyster tissue by year at historic MWP sites.**

### 3.7 TOTAL HEXACHLOROCYCLOHEXANES (HCHs)

There was only one HCH detection in this study, at Severn-3 (0.48 ng/dry g) (Table 5, Figure 21). HCHs were not detected in any of the wild oyster tissue.

Comparisons with Other Data and Guidelines. There are not enough HCH detections nationwide to reliably calculate the national MWP 50th and 85th percentiles for Total HCHs concentrations. The only HCH compound detected, Gamma-HCH, is the only congener for which the EPA has determined SVs. However, the concentration at Severn-3 did not exceed EPA SV values (Appendix 5).

Land-use Analysis. The differences between river tissue concentrations was not significant for Total HCHs (p-value = 0.26).

Trend Analysis. Total HCHs has similar temporal trend pattern as other chlorinated manmade pesticides like DDT. Although site-specific temporal trends fluctuated, the moving average analysis showed an overall consistent decreasing trend over the monitoring years in the Chesapeake Bay (Figure 22A and B).

# Results

Summary of HCHs in oyster tissue. The presence of gamma-HCH at a single site and at a low concentration does not support any meaningful interpretations, except that overall concentrations in the Chesapeake Bay have decreased over time and are almost all at concentration levels below detection limits. The moving average analysis showed that Total HCH pesticides have consistently decreased in concentration over the monitoring years in the Chesapeake Bay (Figure 22A and B). As in the case of other organochlorine compounds, the substantial decrease of the HCH pesticides in the Chesapeake Bay is linked to the regulations that banned these chemicals since the 70's.

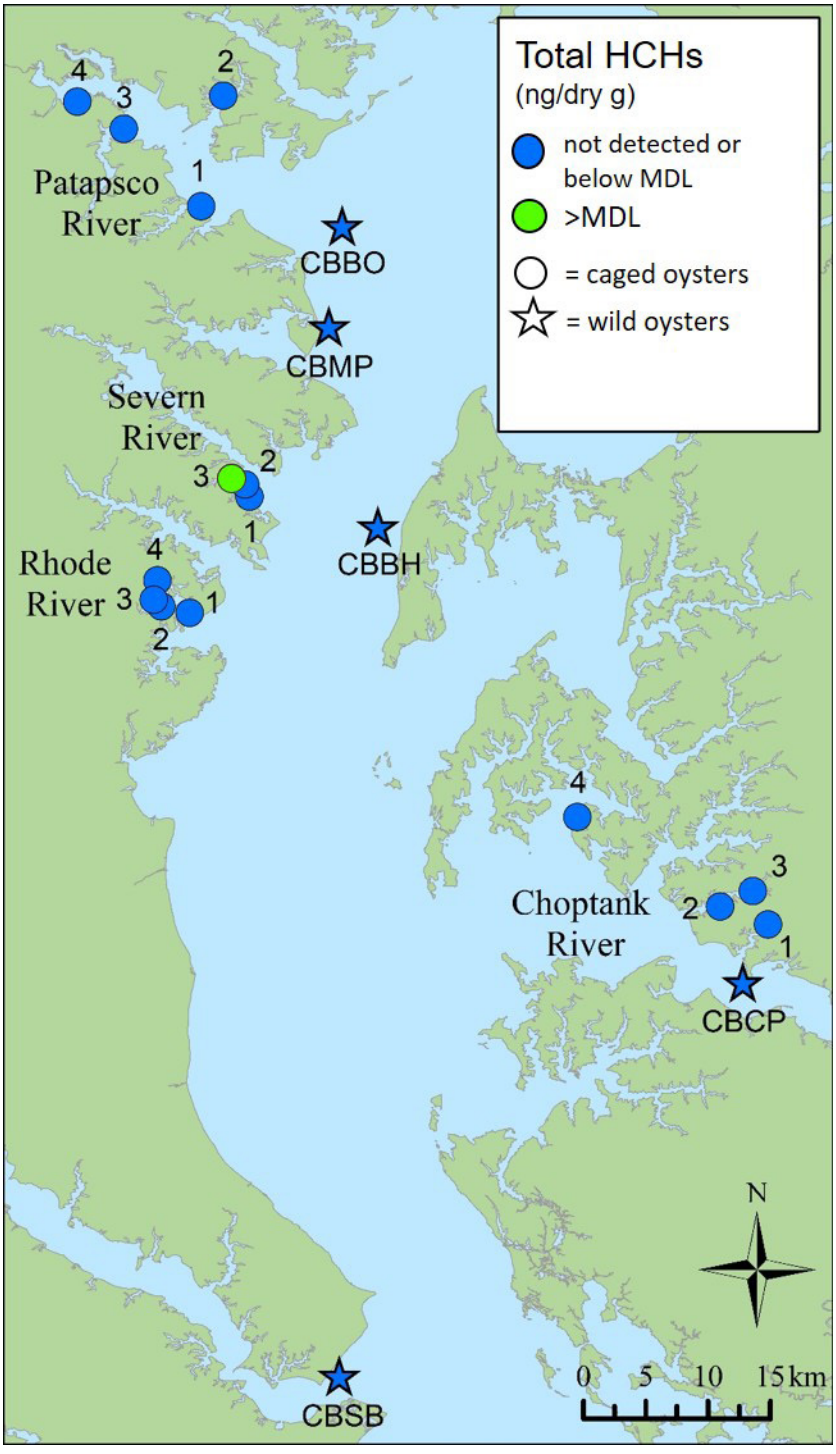


**Figure 21. Total HCHs oyster tissue concentration detections that were above MDL.**

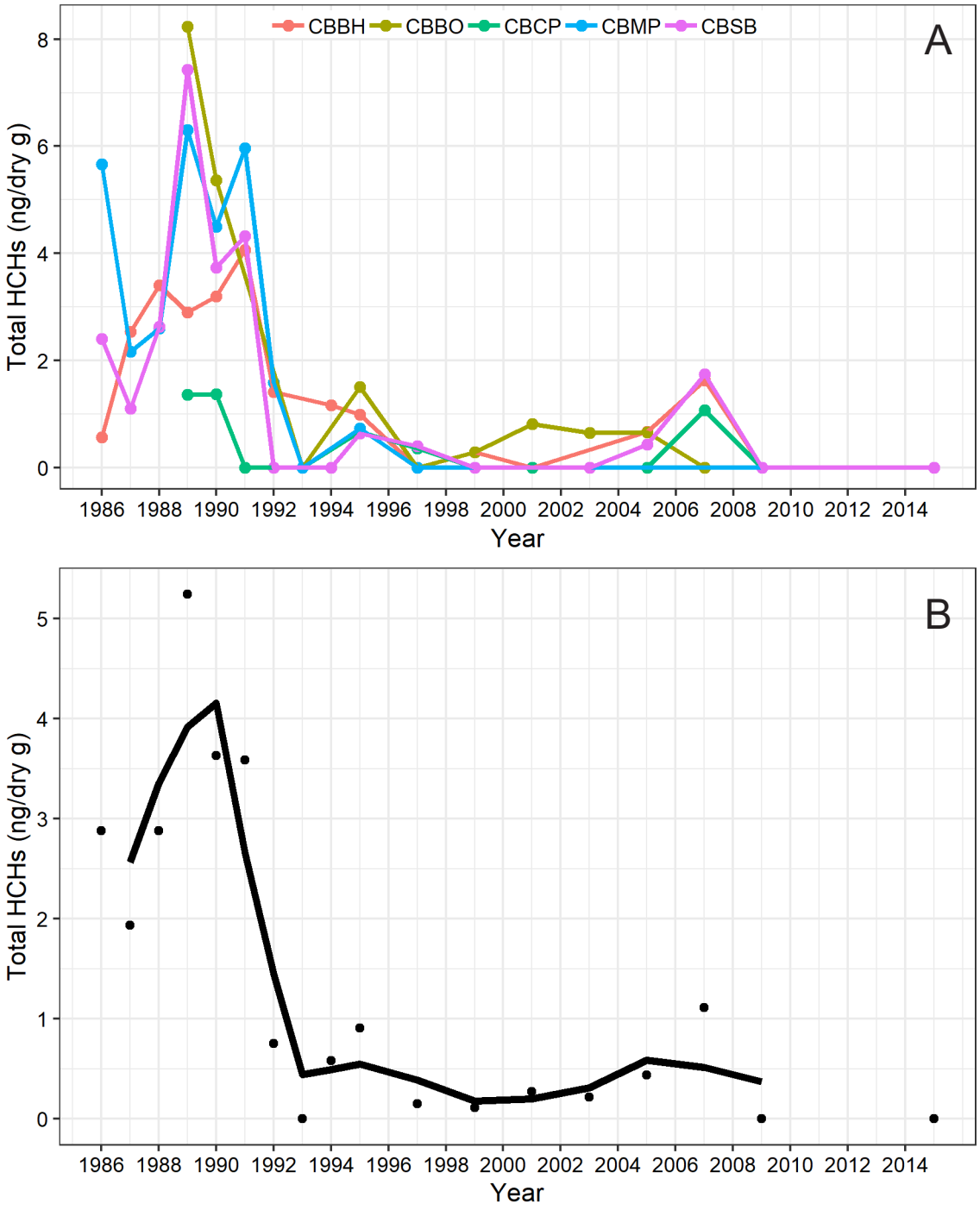


**Figure 22. A: Total HCHs concentrations in wild oyster tissue by year at historic MWP sites. B: Moving average showing the overall temporal trends of Total HCH in in the Chesapeake Bay study area.**

### 3.8 MIREX

Mirex was detected at only four caged oyster sites in the Chesapeake Bay study area, Patapsco-3 and 4, Choptank-2 and Rhode-4 (Table 5, Figure 23). The highest Mirex concentration value (2.56 ng/dry g) was found at Patapsco-4 site in Masonville Cove. The mean value of Mirex in caged oysters was 0.59 ± 0.27 ng/dry g (mean ± SE) (Appendix 4). Mirex was not detected in any of the wild oyster tissue.

Comparisons with Other Data and Guidelines. Mirex contaminants are rarely detected in the US coastal ecosystems outside the Great Lakes, hence the national MWP 50th and 85th percentiles for Mirex could not be reliably derived. None of the concentrations detected in the Chesapeake Bay exceeded either FDA or EPA guidelines (Appendix 5).

Land-use Analysis. There was no significant difference between river tissue concentrations (p-value = 0.5).

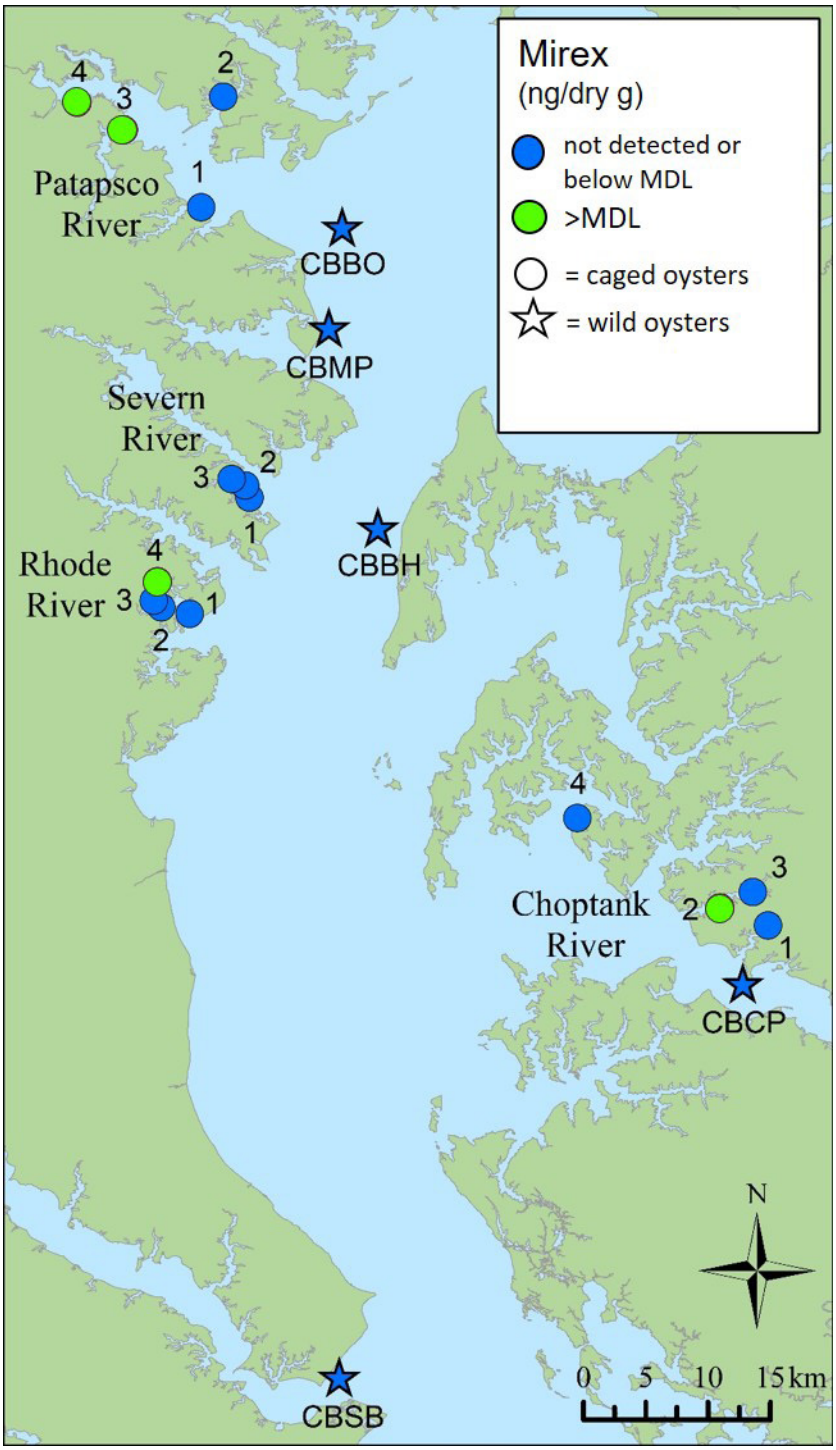


**Figure 23. Mirex oyster tissue concentration detections that were above MDL.**

# Results

Trend Analysis. Aside from some site-specific detections in the early years, Mirex compound has been mostly undetected in the Chesapeake Bay. Mirex has been banned, but the long-term data showed no particular temporal trend due to the low detection rates (Figure 24A and B).

Summary of Mirex in oyster tissue. Since Mirex has not been manufactured or used in the US since 1978, and it breaks down slowly in the environment, any detected concentrations are probably due to residual chemicals rather than any new sources. The long-term data showed no particular temporal trend for Mirex in the Chesapeake Bay (Figure 24A and B).

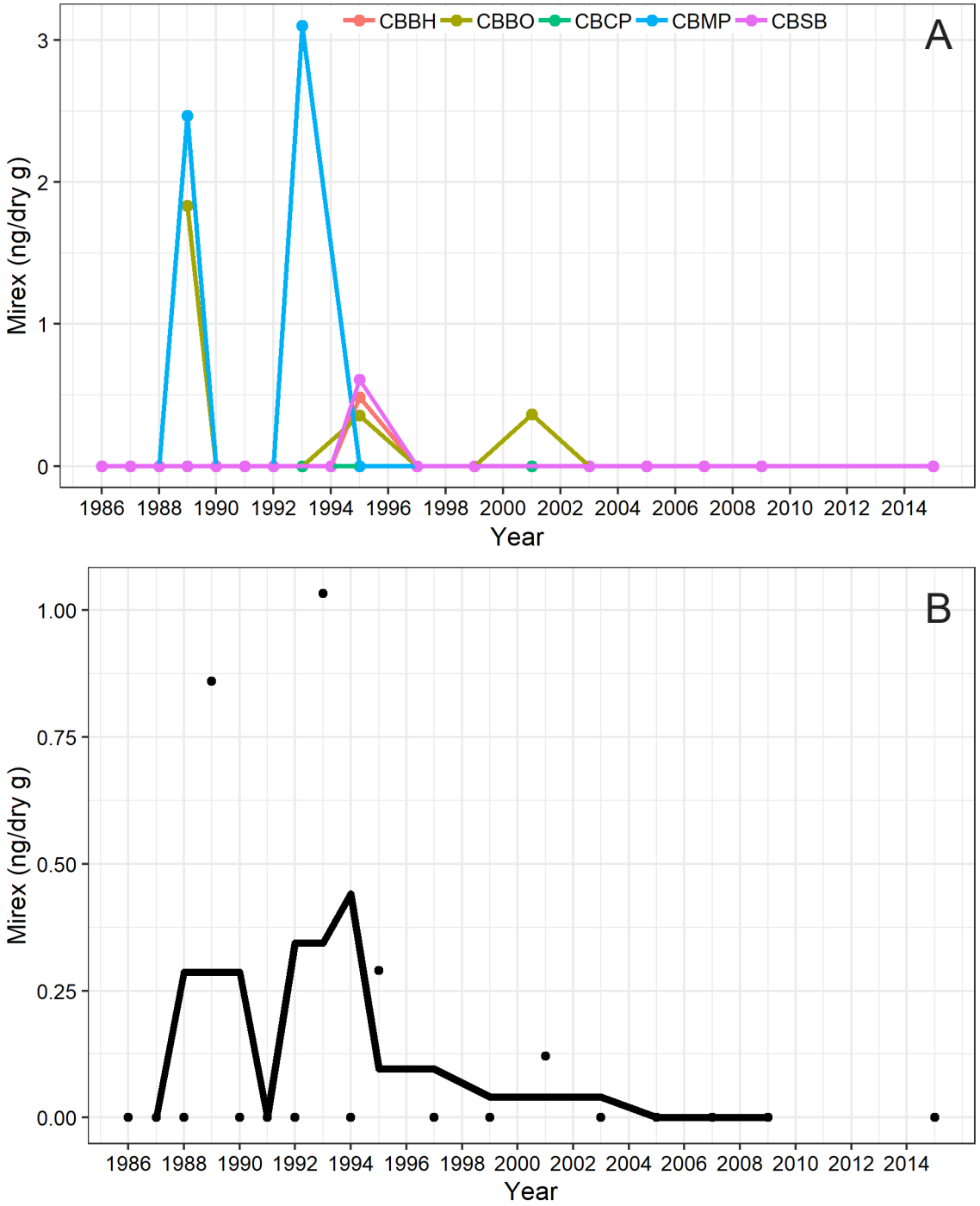


**Figure 24. A: Mirex concentrations in wild oyster tissue by year at historic MWP sites. B: Moving average showing the overall temporal trends of Mirex in in the Chesapeake Bay study area.**

### 3.9 TOTAL POLYCYCLIC AROMATIC HYDROCARBONS (PAHs)

Total PAHs in the Chesapeake Bay caged oyster tissue had a maximum value of 3,249.01 ng/dry g found at Patapsco-4 (Table 5). The next two highest Total PAH concentrations were found at Severn-3 (1,695.59 ng/dry g) and Patapsco-1 (1,526.10 ng/dry g). The mean value of Total PAHs in caged oyster tissue was 771.56 ± 232.70 ng/dry g (mean ± SE) (Appendix 4). Total PAHs in the Chesapeake Bay wild oyster tissue had a maximum value of 313.55 ng/dry g found at CBBO. The next highest Total PAH con-

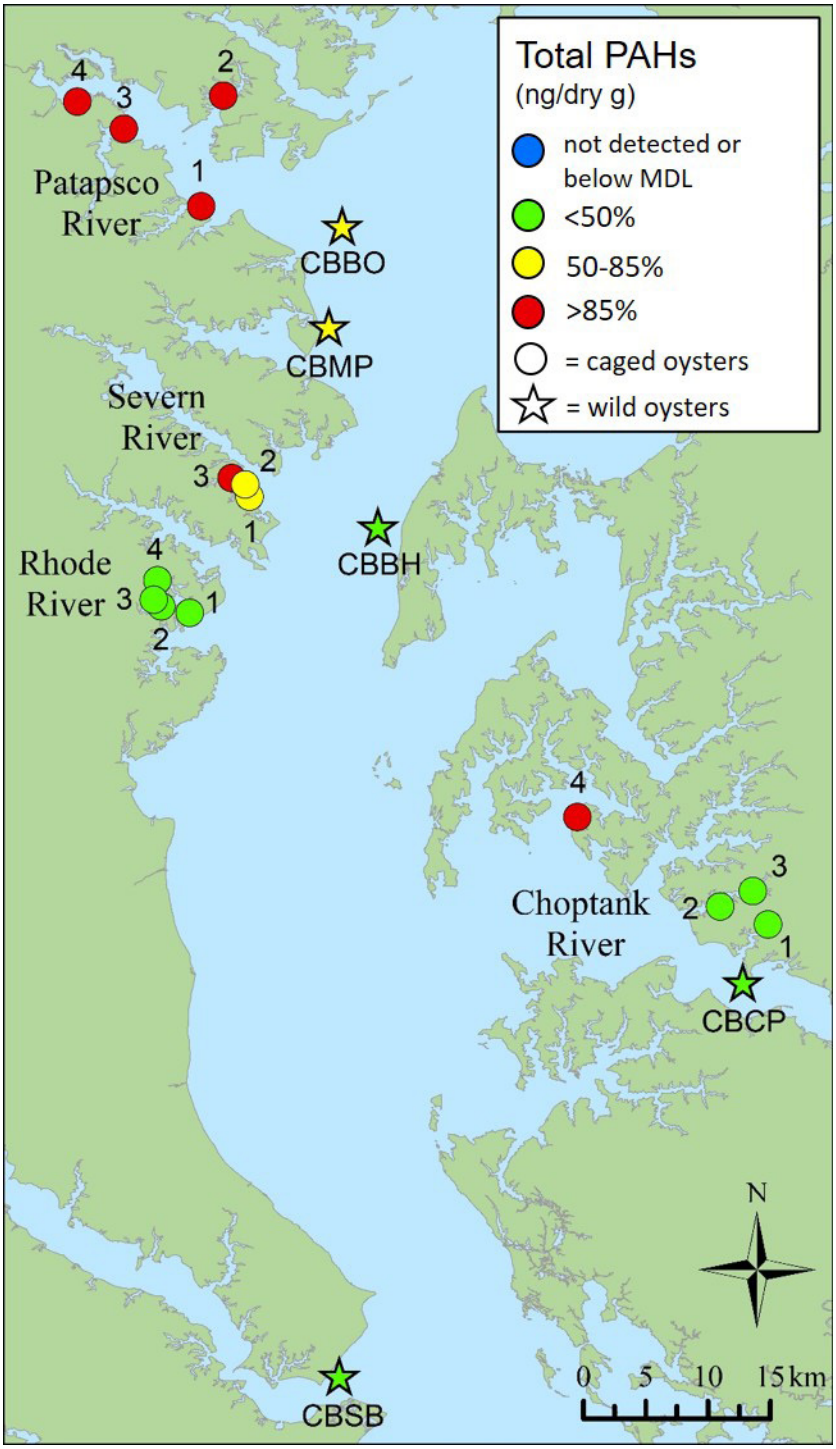


**Figure 25. Total PAH oyster tissue concentrations in comparison to the national MWP 50th and 85th percentiles (137.50 ng/dry g and 715.98 ng/dry g respectively).**

centration was found at CBMP (244.54 ng/dry g). The mean value of Total PAHs in wild oyster tissue was 140.16 ± 57.86 ng/dry g (mean ± SE). Fluoranthene was the dominant compound in the Chesapeake Bay, followed by Chrysene/Triphenylene and Benzo(b)fluoranthene (Appendix 6).

Comparisons with Other Data and Guidelines. To accurately compare Total PAHs data from this study with national MWP 50th and 85th percentiles, a subset of the 64 congeners in this study that directly match the 58 historical congeners were summed. The national MWP 50th and 85th percentiles for Total PAH data are currently calculated as 137.50 ng/dry g and 715.98 ng/dry g respectively. The oyster tissue concentrations at all four Patapsco sites, as well as Severn-3 and Choptank-4, exceeded the national 85th percentile (Figure 24). The remaining two Severn River sites exceeded the 50th percentile. Of the wild oyster sites, only CBBO and CBMP were above the 50th percentile but they remained under the 85th percentile. The concentration for benzo(a)pyrene and Total PAHs in caged oyster tissue exceeded the EPA SV for subsistence fishers at all sites except for Choptank-1. Total PAH values also exceeded the EPA SV for recreational fishers at Patapsco-1, 2 and 4 and Severn-3. Among the wild oyster tissue samples, CBBO was the only sample where the Total PAH values exceeded the EPA SV for subsistence fishers.

Land-use Analysis. There was a significant difference between river concentrations (p-value = 0.02) where the Patapsco River had significantly higher concentrations than the Choptank and Rhode Rivers (Figure 25).

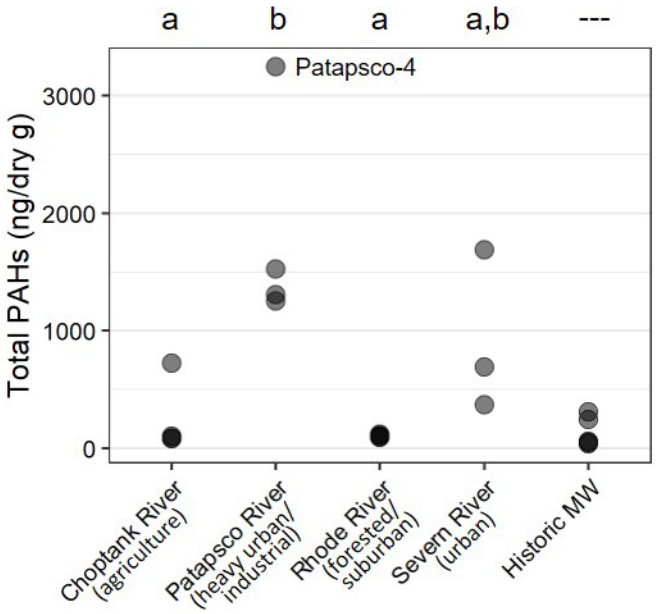


**Figure 26. Total PAH concentrations in caged oyster tissue by river and in wild oyster tissue at the historic MW sites. Letters represent statistical differences between rivers.**

Trend Analysis. Aside from some site-specific detections in the early years, temporal trend assessment of Total PAHs has not yielded any consistent trend pattern over the monitoring years in in the Chesapeake Bay (Figures 27A and B).

Summary of PAHs in oyster tissue. Higher PAH concentrations in oyster tissue were associated with heavy urban/industrial and urban land-use (Figures 25 and 26). The proximity of the two highest Total PAH concentrations to the cities of Baltimore and Annapolis further support the link between urban land-use and PAH concentrations. Both the burning of fossil fuels and organic materials, such as wood and trash, are likely sources of PAHs in these environments. PAHs can also enter the marine environ-

ment by means of discharge from industrial and wastewater treatments plants (ATSDR, 1995b). The concentrations of benzo(a)pyrene and Total PAHs found to be above the EPA SVs are noteworthy since many of these PAHs are likely carcinogens, including the three most dominant compounds fluoranthene, chrysene and benzo(b)fluoranthene. Although many aquatic organisms, like fish, can metabolize PAHs, invertebrates are less able to metabolize them and are more like to bioaccumulate higher concentrations of PAHs. This could contribute to the many exceedances of the EPA SVs. PAH compounds are produced from diverse point and non-point sources that are difficult to regulate and mitigate. Hence, the long-term data showed no particular temporal trend for PAHs in the Chesapeake Bay (Figure 27A and B).

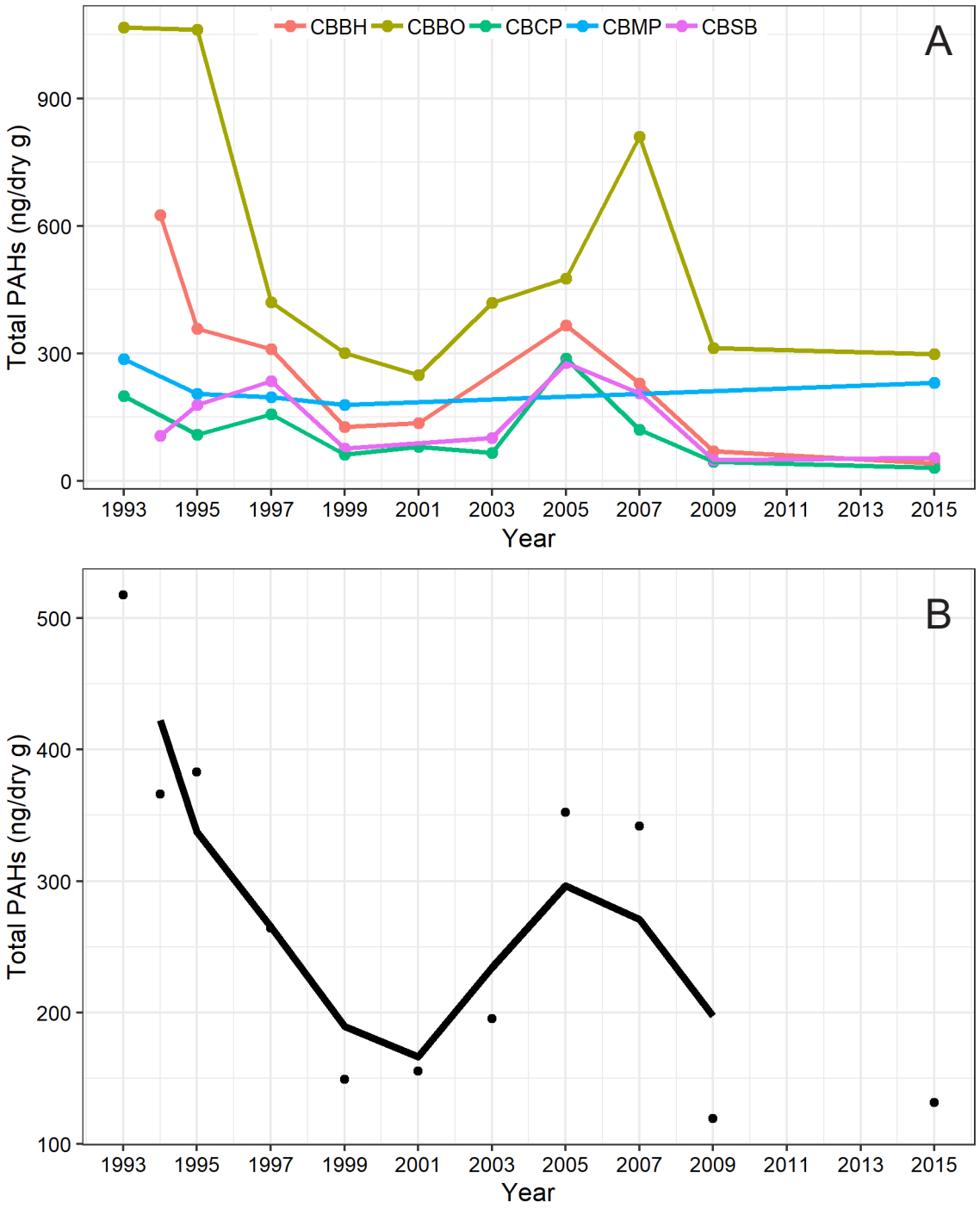


**Figure 27. A: Total PAHs concentrations in wild oyster tissue by year at historic MWP sites. B: Moving average showing the overall temporal trends of Total PAHs in in the Chesapeake Bay study area.**

### 3.10 TOTAL POLYCHLORINATED BIPHENYLS (PCBs)

Total PCBs in the Chesapeake Bay caged oyster tissue had a maximum value of 978.80 ng/dry g at Patapsco-4 (Table 5). The next two highest Total PCB concentrations were also found in the Patapsco River at sites 3 and 2, respectively. The mean value of Total PCBs in caged oyster tissue was 308.36 ± 74.90 ng/dry g (mean ± SE) (Appendix 4). Total PCBs in Chesapeake Bay wild oyster tissue had a maximum value of 143.68 ng/dry g, which occurred at CBMP. The next highest Total PCB concentration in wild oyster tis-

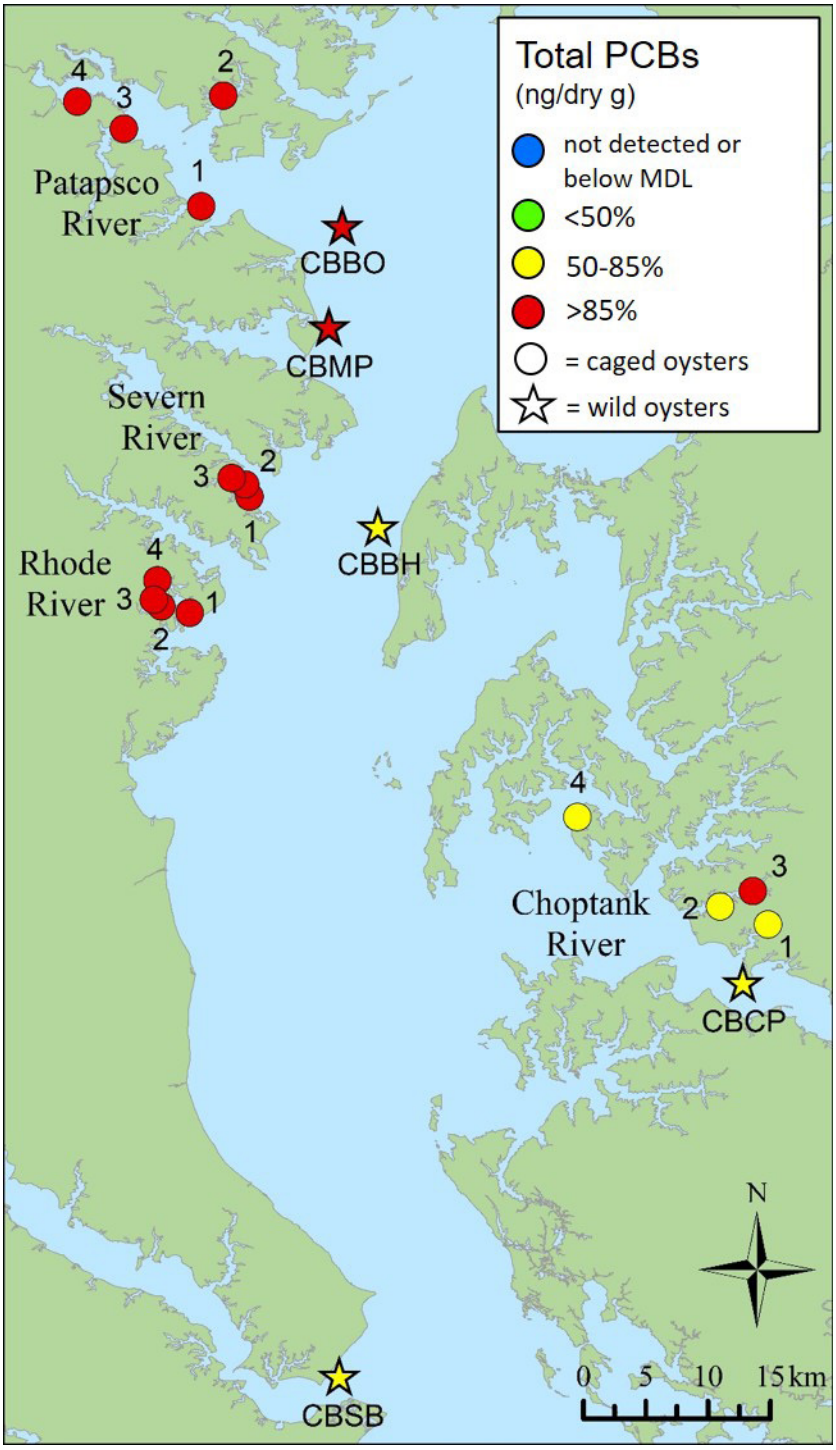


**Figure 28. Total PCB oyster tissue concentrations in comparison to the national MWP 50th and 85th percentiles (15.26 ng/dry g and 75.34 ng/dry g respectively).**

sue was 131.09 ng/dry g found at CBBO. The mean value of Total PCBs in wild oyster tissue was 78.64 ± 24.29 ng/dry g (mean ± SE). Overall, Total PCB concentrations were dominated by PCB153/132 and PCB101/90 in the Chesapeake Bay, though the dominant PCB compound varied by river. The Choptank River was dominated by PCB28 while the Rhode River was dominated by PCB153/132 and PCB28. The two dominant congeners in the Patapsco and Severn Rivers are PCB153/132 and PCB101/90 (Appendix 6).

Comparisons with Other Data and Guidelines. In order to accurately compare Total PCB data from this study with the national MWP 50th and 85th percentiles, a subset of the 86 congeners in this study that directly match the 39 historical congeners was summed. The national MWP 50th and 85th percentiles for Total PCBs data are currently calculated as 15.26 ng/dry g and 75.34 ng/dry g respectively. All but three of the caged oyster sites exceeded the 85th percentile for Total PCBs (Figure 28). The three remaining sites all exceeded the 50th percentile and were located in the Choptank River (sites 1, 2 and 4). All wild oyster sites exceeded the 50th percentile for Total PCBs, and CBBO and CBMP both exceeded the 85th percentile. All of the caged oyster sites exceed the EPA SV for subsistence fishers. All of the Patapsco sites and Severn-2 and 3, also exceeded the EPA SV for recreational fishers. CBBO and CBMP were the only two wild oyster sites to exceed the EPA SV subsistence SV, and no wild oyster samples exceeded the recreational fishers SV.

Land-use Analysis. There was a significant difference between river concentrations (p-value = 0.01). The Patapsco and Severn Rivers had significantly higher concentrations of Total PCBs than the Choptank River, and the Patapsco River was also significantly higher than the Rhode River (Figures 28 and 29).

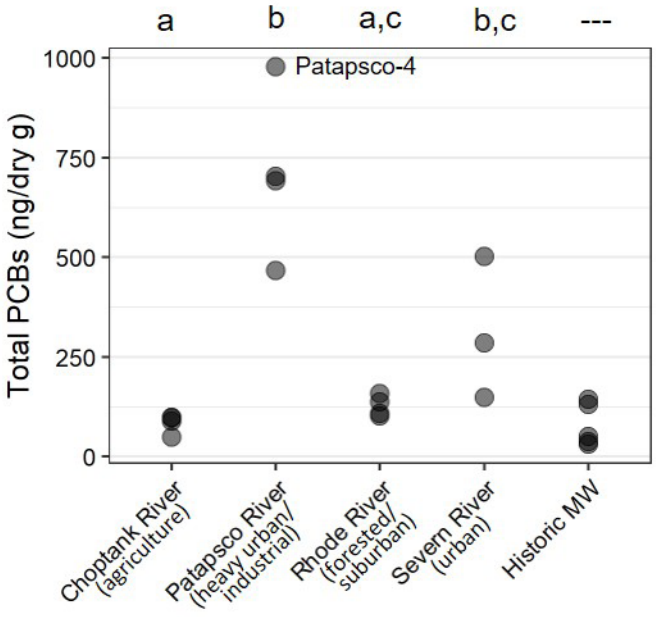


**Figure 29. Total PCB concentrations in caged oyster tissue by river and in wild oyster tissue at the historic MW sites. Letters represent statistical differences between rivers.**

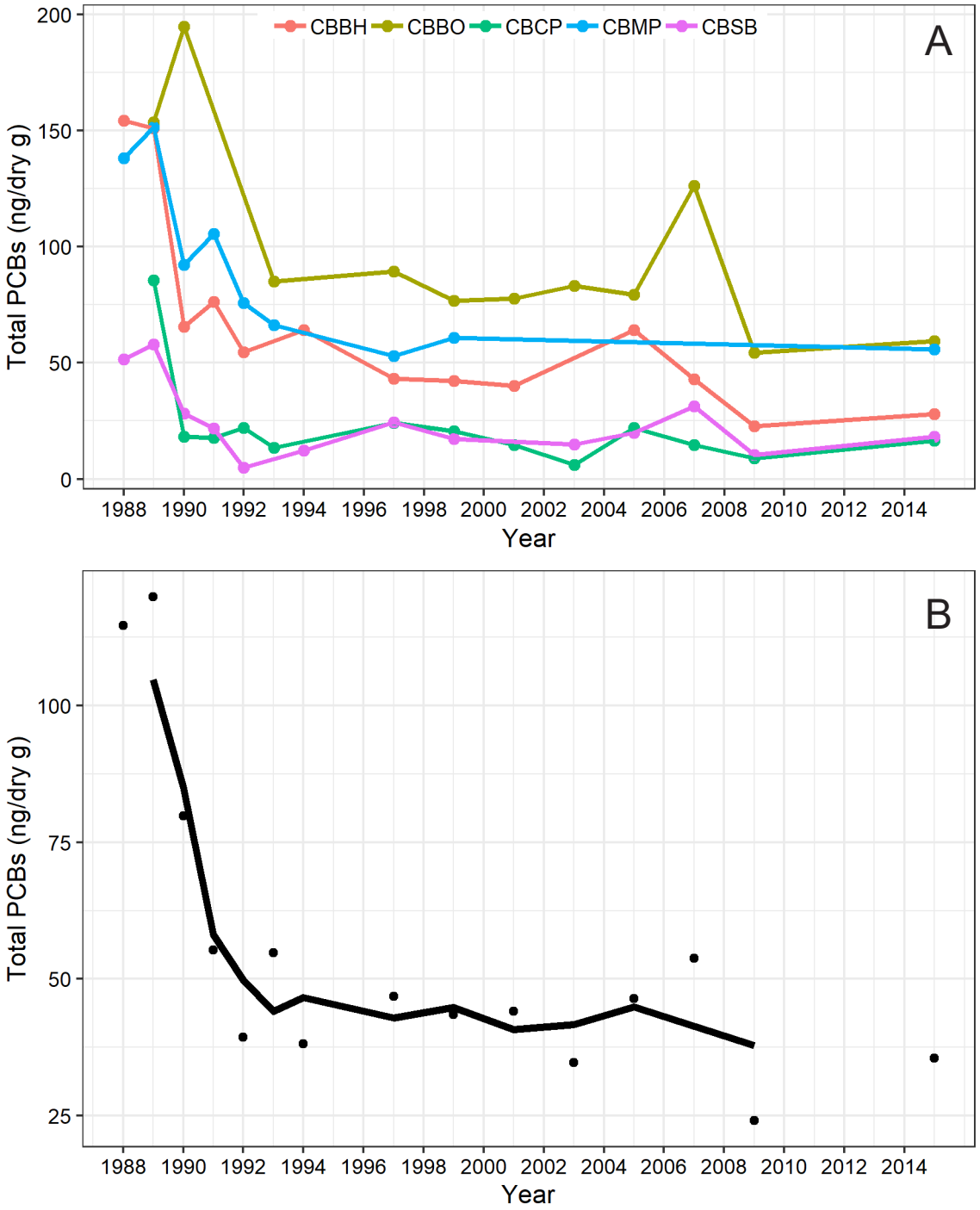


**Figure 30. A: Total PCB concentrations in wild oyster tissue by year at historic MWP sites. B: Moving average showing the overall temporal trends of Total PCBs in in the Chesapeake Bay study area.**

Trend Analysis. The long-term data showed that PCB compounds have similar temporal trend pattern as other anthropogenic compounds like the organochlorine pesticides. Although site-specific temporal trends fluctuated, the moving average analysis indicated an overall consistent decreasing trend over the monitoring years in the Chesapeake Bay (Figure 30A and B).

Summary of PCBs in oyster tissue. Similar to PAHs, the highest concentrations of PCBs are associated with heavy urban/industrial and urban land-use. Since PCBs have been banned from 1979, we can assume there are no new sources of PCBs in this environment. However, there are still many ways that

# Results

PCBs can enter the marine environment, including volatilization from landfills, leaks from old electrical equipment, and dredging of contaminated sediments (WHO & IPCS, 1993). The US EPA believes that manufactured PCB products were widely used during construction and renovation activities between 1950 and 1979. As a result, building materials could also be a source of PCBs, especially during renovations or demolition and as a result of the improper disposal of materials containing PCBs (USEPA, 2021). PCBs bioaccumulate and degrade slowly and are clearly persisting in the estuarine environments of the Chesapeake Bay. PCBs are likely carcinogens (ATSDR, 2000) and have been linked to many other health issues including adversely affecting reproduction, growth, metabolism and survival in animals (Eisler & Belisle, 1996). This study showed that Total PCB concentrations at many sites exceeded both EPA SVs for subsistence and recreational fishers thresholds (Appendix 5). As a result, PCB concentrations in the Chesapeake Bay should be a cause of concern for fish and shellfish consumption. Although the moving average analysis showed that PCB compounds decreased in concentration in the 1980's and '90s, they have shown much smaller decreases in the last two decades in the Chesapeake Bay (Figure 30A and B). As in the case of other manmade toxic chemicals, the substantial decrease of Total PCBs in the Chesapeake Bay is likely linked to regulations that banned these chemicals in the 1970's.

## 4.0 CONCLUSIONS

This study indicated that the Patapsco River, a major tributary of the Chesapeake Bay, was found to be the most contaminated area when compared to the other rivers that were sampled. It had the overall highest concentrations of legacy organic compounds in caged oyster tissue. The Severn and the Patapsco Rivers represent urban and heavy urban/industrial land-uses respectively. Although the detected contaminants varied slightly between the two rivers, there appears to be a link between urbanization and legacy organic contaminants. The highest concentrations were often detected at Patapsco-4, the site closest to Baltimore and at Severn-3, the site closest to Annapolis. The Chesapeake Bay Program had already identified Baltimore Harbor as one of its three “Regions of Concern” in the bay, along with the Anacostia River and Elizabeth River. These areas are all associated with the highest levels of urbanization (US EPA et al., 2012). In 2010, the Chesapeake Bay Program reported that 72% of the bay’s tidal water are considered impaired by toxic contaminants, causing potential harm to both humans and wildlife (US EPA et al., 2012). A 2012 analysis of toxic contaminants in the Chesapeake Bay by the EPA showed that PAHs and PCBs have a widespread extent in the Chesapeake Bay and that other contaminants such as chlorinated insecticides (aldrin, dieldrin, DDT/DDE, chlordane, heptachlor epoxide) have a localized extent (US EPA et al., 2012). However, this study found many of those contaminants at the majority of sites, although at varying concentrations.

Considering the proportion of legacy organic contaminants that were pesticides, one might think that agriculturally based watersheds, such as the Choptank River, would have higher concentrations. However, it appears that residential applications of pesticides have a stronger influence on the environmental concentrations than those caused by the agricultural activities in the Choptank watershed. Almost all of these compounds are no longer produced and current concentrations are residual and persistent concentrations from previous environmental inputs.

While close proximity to different watersheds and river mouths is probably driving the concentration differences between the historic MWP sites, several other factors may be affecting the persistence of these contaminants. The local hydrology, water column stratification and the hypoxic conditions observed in the bottom water at some of the sites could be affecting contaminant breakdown and biodegradation, thereby impacting their fate and transport and exposure to marine organisms. When not exposed to biodegradation, chemicals can remain attached to deep water sediment particles for decades providing diffused but continuous sources of contamination.

In general, legacy organic contaminants appeared to be decreasing in the Chesapeake Bay ecosystem. This decrease could be linked to positive impacts of regulations enacted since the 1970’s. The Clean Water Act and Clean Air Act are examples of such regulation that banned or regulate the production, application, and discharge of many of these manmade toxic chemical compounds. In the Chesapeake Bay the decreasing trend may also be the result of state, non-government organizations (NGOs), and local agencies implementing best management practices aimed at reducing pollution in the bay’s watersheds. Baltimore Harbor in particular has been the focus of many initiatives and grants, such as the Chesapeake Bay Program, to help improve the ecological conditions in its watershed. However, the persistent presence of some of these contaminants in the Chesapeake Bay environment at levels above guidelines raises concern. Hence, the need for continued monitoring to further evaluate trends in these chemicals and ensure that safety standards can be communicated to the public. As state and Federal organizations continue mitigation and restoration efforts, this MWP study provides relevant scientific data that could be leveraged by resource managers to fill chemical contaminant data gaps in support of the bay’s restoration efforts.

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Appendix 1. Field data collected from the Chesapeake Bay, MD, 2015 study.

| Site Name | Specific Location | MWP Site Code | Matrix | Latitude | Longitude | Deployment Date | Collection/ Recovery Date | Depth (ft) | Surface Temp. (°C) | Bottom Temp. (°C) | Surface Salinity (ppt) | Bottom Salinity (ppt) | Surface DO (mg/L) | Bottom DO (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Choptank-1 | LaTrappe Creek | CBCT-1 | caged oyster (CV) | 38.65124 | -76.09811 | 6/22/2015 | 8/27/2015 | 3.5 | 27.3 | 27.3 | 10.34 | 10.35 | 4.72 | 4.73 |
| Choptank-2 | Island Creek | CBCT-2 | caged oyster (CV) | 38.66423 | -76.13267 | 6/22/2015 | 8/27/2015 | 4.8 | 27.2 | 27.2 | 11.25 | 11.26 | 6.45 | 5.64 |
| Choptank-3 | Island Creek | CBCT-3 | caged oyster (CV) | 38.67537 | -76.10911 | 6/22/2015 | 8/27/2015 | 4.5 | 27.4 | 27.3 | 11.02 | 11.03 | 6.24 | 4.31 |
| Choptank-4 | Broad Creek | CBCT-4 | caged oyster (CV) | 38.72881 | -76.23573 | 6/22/2015 | 8/27/2015 | 4 | 25.8 | 25.8 | 11.69 | 11.69 | 9.7 | 9.48 |
| Patapsco-1 | Riviera Beach | CBPT-1 | caged oyster (CV) | 39.16925 | -76.50734 | 6/23/2015 | 8/26/2015 | 3 | 25.1 | 25.1 | 7.33 | 7.39 | 6.97 | 6.72 |
| Patapsco-2 | Bear Creek | CBPT-2 | caged oyster (CV) | 39.24897 | -76.49134 | 6/23/2015 | 8/26/2015 | 8 | 26.9 | 26.9 | 6.55 | 8.52 | 7.86 | 1.51 |
| Patapsco-3 | Curtis Bay | CBPT-3 | caged oyster (CV) | 39.22500 | -76.56327 | 6/23/2015 | 8/26/2015 | 3.2 | 26.4 | 26.3 | 7.44 | 7.65 | 9.65 | 10.66 |
| Patapsco-4 | Masonville Cove | CBPT-4 | caged oyster (CV) | 39.24464 | -76.59678 | 6/23/2015 | 8/26/2015 | 5.9 | 26.2 | 26.5 | 4.44 | 6.53 | 11.32 | 1.83 |
| Rhode-1 | Locust Point | CBRD-1 | caged oyster (CV) | 38.87605 | -76.51576 | 6/29/2015 | 8/27/2015 | | 26.5 | 26.5 | 10.06 | 10.06 | 7.79 | 7.79 |
| Rhode-2 | O'Neill Island | CBRD-2 | caged oyster (CV) | 38.88062 | -76.53606 | 6/29/2015 | 8/27/2015 | | 26.8 | 26.7 | 9.75 | 9.76 | 6.4 | 6.34 |
| Rhode-3 | Forrest Branch | CBRD-3 | caged oyster (CV) | 38.88559 | -76.54160 | 6/29/2015 | 8/27/2015 | | 26.8 | 26.8 | 9.56 | 9.56 | 4.09 | 4.09 |
| Rhode-4 | Sellman Creek | CBRD-4 | caged oyster (CV) | 38.89943 | -76.53891 | 6/29/2015 | 8/27/2015 | | 26.1 | 26.1 | 9.48 | 9.48 | 6.91 | 6.91 |
| Severn-1 | Harbor Marina | CBSV-1 | caged oyster (CV) | 38.95974 | -76.47249 | 6/24/2015 | 8/31/2015 | | 25.9 | 25.9 | 9.92 | 9.92 | 4.79 | 4.79 |
| Severn-2 | Back Creek | CBSV-2 | caged oyster (CV) | 38.96858 | -76.47571 | 6/24/2015 | 8/31/2015 | | 26.3 | 26.3 | 9.58 | 9.58 | 3.98 | 3.98 |
| Severn-3 | Spa Creek | CBSV-3 | caged oyster (CV) | 38.97328 | -76.48536 | 6/24/2015 | 8/31/2015 | | 26.8 | 26.8 | 9.05 | 9.05 | 5 | 5 |
| CBBH | Brick House | CBBH | wild oyster(CV) | 38.93860 | -76.37976 | *na* | 8/24/2015 | 34 | 26.5 | 26.4 | 9.65 | 14.5 | 7.64 | 2.2 |
| CBBO | Bodkin Point | CBBO | wild oyster(CV) | 39.15541 | -76.40548 | *na* | 8/25/2015 | 16 | 26.4 | 26.5 | 7.2 | 9.15 | 6.72 | 2.78 |
| CBCP | Choptank River | CBCP | wild oyster(CV) | 38.60978 | -76.11631 | *na* | 8/25/2015 | 9 | 27.6 | 27.3 | 10.09 | 10.79 | 7.02 | 6.27 |
| CBMP | Mountain Point | CBMP | wild oyster(CV) | 39.08279 | -76.41517 | *na* | 8/25/2015 | 17.5 | 26.3 | 26.3 | 7.77 | 8.6 | 5.62 | 4.3 |
| CBSB | Simmons Bar | CBSB | wild oyster(CV) | 38.32589 | -76.40762 | *na* | 8/26/2015 | | 26.7 | 26.8 | 12.91 | 13.21 | 6.35 | 6.15 |

Notes: MWP, Mussel Watch Program; CV, Crassostrea virginica; DO, dissolved oxygen

**Appendix 2. Percent dry values and percent lipid values for oysters in the Chesapeake Bay, MD.**

| Site Name | Matrix | % Dry | % Lipid (dry) |
|---|---|---|---|
| Choptank-1 | tissue | 14 | 17.8 |
| Choptank-2 | tissue | 15 | 17.1 |
| Choptank-3 | tissue | 14 | 22.5 |
| Choptank-4 | tissue | 13 | 21.5 |
| Patapsco-1 | tissue | 16 | 16.9 |
| Patapsco-2 | tissue | 16 | 17.1 |
| Patapsco-3 | tissue | 15 | 18.2 |
| Patapsco-4 | tissue | 15 | 17.3 |
| Rhode-1 | tissue | 15 | 19.5 |
| Rhode-2 | tissue | 14 | 20.2 |
| Rhode-3 | tissue | 14 | 19.4 |
| Rhode-4 | tissue | 16 | 21.1 |
| Severn-1 | tissue | 16 | 18.9 |
| Severn-2 | tissue | 15 | 18.1 |
| Severn-3 | tissue | 14 | 17.8 |
| CBBH | tissue | 7 | 15.0 |
| CBBO | tissue | 8 | 8.30 |
| CBCP | tissue | 8 | 11.1 |
| CBMP | tissue | 8 | 12.4 |
| CBSB | tissue | 9 | 11.7 |

Notes: conc. ng/g dry * (% Dry/100) = conc. ng/g wet

## Appendix 3. Method detection limits (MDL) for oyster tissue samples (ng/dry g).

| Compound | MDL (tissue) | Compound | MDL (tissue) | Compound | MDL (tissue) | Compound | MDL (tissue) |
|---|---|---|---|---|---|---|---|
| Monobutyltin | 1.105 | PCB22/51 | 0.400 | PCB146 | 0.596 | Acenaphthylene | 1.084 |
| Dibutyltin | 1.105 | PCB24/27 | 0.400 | PCB149/123 | 0.596 | Acenaphthene | 3.985 |
| Tributyltin | 1.105 | PCB25 | 0.400 | PCB151 | 0.596 | Dibenzofuran | 1.335 |
| Tetrabutyltin | 1.105 | PCB26 | 0.400 | PCB153/132 | 0.309 | Fluorene | 1.052 |
| | | PCB28 | 0.426 | PCB156/171/202 | 0.596 | C1-Fluorenes | 2.104 |
| Aldrin | 0.217 | PCB29 | 0.288 | PCB158 | 0.596 | C2-Fluorenes | 2.104 |
| Dieldrin | 0.241 | PCB31 | 0.400 | PCB166 | 0.596 | C3-Fluorenes | 2.104 |
| Endrin | 0.380 | PCB33/53/20 | 0.400 | PCB167 | 0.596 | Carbazole | 2.038 |
| | | PCB40 | 0.391 | PCB169 | 0.596 | Anthracene | 0.813 |
| Heptachlor | 0.228 | PCB41/64 | 0.391 | PCB170/190 | 0.367 | Phenanthrene | 1.875 |
| Heptachlor-Epoxide | 0.240 | PCB42/59/37 | 0.391 | PCB172 | 0.293 | C1-Phenanthrenes/Anthracenes | 0.753 |
| Oxychlordane | 0.211 | PCB43 | 0.391 | PCB174 | 0.293 | C2-Phenanthrenes/Anthracenes | 2.628 |
| Alpha-Chlordane | 0.249 | PCB44 | 0.391 | PCB176/137 | 0.293 | C3-Phenanthrenes/Anthracenes | 2.628 |
| Gamma-Chlordane | 0.242 | PCB45 | 0.391 | PCB177 | 0.293 | C4-Phenanthrenes/Anthracenes | 2.628 |
| Trans-Nonachlor | 0.240 | PCB46 | 0.391 | PCB178 | 0.293 | Dibenzothiophene | 0.320 |
| Cis-Nonachlor | 0.211 | PCB47/48/75 | 0.391 | PCB180 | 0.293 | C1-Dibenzothiophenes | 0.874 |
| | | PCB49 | 0.391 | PCB183 | 0.293 | C2-Dibenzothiophenes | 0.640 |
| Alpha-HCH | 0.250 | PCB52 | 0.391 | PCB185 | 0.293 | C3-Dibenzothiophenes | 0.640 |
| Beta-HCH | 0.272 | PCB56/60 | 0.391 | PCB187 | 0.207 | C4-Dibenzothiophenes | 0.640 |
| Delta-HCH | 0.231 | PCB66 | 0.312 | PCB189 | 0.293 | Fluoranthene | 1.405 |
| Gamma-HCH | 0.258 | PCB70 | 0.391 | PCB191 | 0.293 | Pyrene | 0.669 |
| | | PCB74/61 | 0.391 | PCB194 | 0.302 | C1-Fluoranthenes/Pyrenes | 2.074 |
| 2,4'-DDD | 0.254 | PCB77 | 0.391 | PCB195/208 | 0.302 | C2-Fluoranthenes/Pyrenes | 2.074 |
| 4,4'-DDD | 0.241 | PCB81 | 0.391 | PCB196/203 | 0.302 | C3-Fluoranthenes/Pyrenes | 2.074 |
| 2,4'-DDE | 0.235 | PCB82 | 0.419 | PCB199 | 0.503 | C4-Fluoranthenes/Pyrenes | 2.074 |
| 4,4'-DDE | 0.279 | PCB83 | 0.419 | PCB200 | 0.302 | Naphthobenzothiophene | 0.595 |
| 2,4'-DDT | 0.259 | PCB84 | 0.419 | PCB201/157/173 | 0.302 | C1-Naphthobenzothiophenes | 1.190 |
| 4,4'-DDT | 0.216 | PCB85 | 0.419 | PCB205 | 0.302 | C2-Naphthobenzothiophenes | 1.190 |
| | | PCB86 | 0.419 | PCB206 | 0.346 | C3-Naphthobenzothiophenes | 1.190 |
| 1,2,3,4-Tetrachlorobenzene | 0.262 | PCB87/115 | 0.307 | PCB209 | 0.305 | C4-Naphthobenzothiophenes | 1.190 |
| 1,2,4,5-Tetrachlorobenzene | 0.237 | PCB88 | 0.419 | | | Benz(a)anthracene | 0.325 |
| Hexachlorobenzene | 0.293 | PCB92 | 0.419 | cis/trans Decalin | 6.551 | Chrysene/Triphenylene | 0.714 |
| Pentachloroanisole | 0.253 | PCB95 | 0.419 | C1-Decalins | 13.102 | C1-Chrysenes | 1.428 |
| Pentachlorobenzene | 0.229 | PCB97 | 0.419 | C2-Decalins | 13.102 | C2-Chrysenes | 1.428 |
| | | PCB99 | 0.419 | C3-Decalins | 13.102 | C3-Chrysenes | 1.428 |
| Endosulfan II | 0.250 | PCB101/90 | 0.419 | C4-Decalins | 13.102 | C4-Chrysenes | 1.428 |
| Endosulfan I | 0.255 | PCB105 | 0.353 | Naphthalene | 12.438 | Benzo(b)fluoranthene | 0.477 |
| Endosulfan Sulfate | 0.260 | PCB107 | 0.419 | C1-Naphthalenes | 0.690 | Benzo(k,j)fluoranthene | 0.888 |
| | | PCB110/77 | 0.277 | C2-Naphthalenes | 24.876 | Benzo(a)fluoranthene | 0.888 |
| Mirex | 0.224 | PCB114/131/122 | 0.419 | C3-Naphthalenes | 24.876 | Benzo(e)pyrene | 0.822 |
| | | PCB118 | 0.333 | C4-Naphthalenes | 24.876 | Benzo(a)pyrene | 0.889 |
| PCB1 | 0.432 | PCB126 | 0.419 | Benzothiophene | 0.825 | Perylene | 5.051 |
| PCB7/9 | 0.432 | PCB128 | 0.425 | C1-Benzothiophenes | 1.650 | Indeno(1,2,3-c,d)pyrene | 1.259 |
| PCB8/5 | 0.432 | PCB129/126 | 0.596 | C2-Benzothiophenes | 1.650 | Dibenzo(a,h)anthracene | 1.114 |
| PCB15 | 0.432 | PCB136 | 0.596 | C3-Benzothiophenes | 1.650 | C1-Dibenzo(a,h)anthracenes | 2.229 |
| PCB16/32 | 0.400 | PCB138/160 | 0.596 | C4-Benzothiophenes | 1.650 | C2-Dibenzo(a,h)anthracenes | 2.229 |
| PCB18 | 0.400 | PCB141/179 | 0.596 | Biphenyl | 3.178 | C3-Dibenzo(a,h)anthracenes | 2.229 |
| | | | | | | Benzo(g,h,i)perylene | 0.737 |

Notes: MDL, method detection limit; DDT, dichlorodiphenyltrichloroethane; DDD, dichlorodiphenyldichloroethane; DDE, dichlorodiphenyldichloroethylene; HCH, hexachlorocyclohexane; PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl

**Appendix 4. Mean, standard error, minimum and maximum total contaminant group concentrations in caged oysters and wild oysters in the Chesapeake Bay, MD (ng/dry g).**

| | caged oysters (n=15) | | | wild oysters (n=5) | | |
|---|---|---|---|---|---|---|
| Compound Group | Mean ± SE | Min. | Max. | Mean ± SE | Min. | Max. |
| Total Butyltins | 46.98 ± 21.71 | 1.50 | 327.23 | 68.75 ± 18.37 | 0.00 | 102.78 |
| Total Chlordanes | 37.63 ± 14.10 | 4.79 | 214.14 | 7.89 ± 1.17 | 4.94 | 11.09 |
| Total Chlorobenzenes | 2.15 ± 0.50 | 0.00 | 6.45 | 2.47 ± 0.56 | 1.55 | 4.68 |
| Total DDTs | 35.01 ± 11.48 | 7.17 | 188.54 | 10.05 ± 2.26 | 5.07 | 16.22 |
| Total Dieldrins | 9.13 ± 2.92 | 0.00 | 39.58 | 2.03 ± 0.34 | 1.24 | 3.03 |
| Total Endosulfans | 0.00 ± 0.00 | 0.00 | 0.00 | 0.00 ± 0.00 | 0.00 | 0.00 |
| Total HCHs | 0.03 ± 0.03 | 0.00 | 0.48 | 0.00 ± 0.00 | 0.00 | 0.00 |
| Mirex | 0.59 ± 0.27 | 0.00 | 2.56 | 0.00 ± 0.00 | 0.00 | 0.00 |
| Total PAHs | 771.56 ± 232.70 | 83.49 | 3249.01 | 140.16 ± 57.86 | 35.64 | 313.55 |
| Total PCBs | 308.36 ± 74.90 | 49.93 | 978.80 | 78.64 ± 24.29 | 30.38 | 143.68 |

Notes: SE, standard error; Min., minimum; Max., maximum; DDT, dichlorodiphenyltrichloroethane; HCH, hexachlorocyclohexane; PAH, polycyclic aromatic

**Appendix 5. Individual and total contaminant concentrations in oyster tissue per site in the Chesapeake Bay, MD calculated for comparison with USFDA Action and Tolerance levels and USEPA Screening Values (SVs) for chemical contaminants in fish and shellfish (ng/g wet weight) (USFDA, 2011; USEPA, 1994).**

| | Tributyltin | Aldrin | Dieldrin | Endrin | Endosulfan (I and II) | Heptachlor/ Heptachlor epoxide | Hexachlorobenzene | Lindane[a] | Mirex | PAHs[b] (benzo(a)pyrene) | Total PAHs[b] | Total Chlordane[c] | Total DDT[d] | Total PCBs[e] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Choptank-1 | 0.25 | 0.00 | 0.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.33 | 0.51 | 1.00 | 2.13 | **6.97** |
| Choptank-2 | 0.23 | 0.00 | 0.25 | 0.00 | 0.00 | 0.07 | 0.00 | 0.00 | 0.38 | **0.71** | **0.91** | 1.08 | 1.93 | **6.23** |
| Choptank-3 | 0.16 | 0.00 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **2.44** | **2.59** | 1.48 | 3.70 | **6.76** |
| Choptank-4 | 0.30 | 0.00 | 0.22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **1.91** | **2.79** | 0.62 | 0.93 | **3.95** |
| Patapsco-1 | 2.04 | **0.35** | **2.40** | 0.00 | 0.00 | 0.32 | 0.00 | 0.00 | 0.00 | **2.91** | **8.85*** | 8.37 | 5.55 | **30.40*** |
| Patapsco-2 | 1.57 | **0.33** | **2.37** | 0.07 | 0.00 | 0.48 | 0.00 | 0.00 | 0.00 | **1.50** | **6.78*** | 8.61 | 3.50 | **45.08*** |
| Patapsco-3 | 1.91 | 0.00 | **3.77*** | 0.10 | 0.00 | **0.68** | 0.00 | 0.00 | 0.38 | **1.23** | **4.82** | 12.27 | 8.81 | **47.71*** |
| Patapsco-4 | 0.90 | **0.62** | **5.28*** | 0.00 | 0.00 | **0.77** | 0.00 | 0.00 | 0.38 | **2.44** | **10.80*** | **31.12** | **28.08** | **61.65*** |
| Rhode-1 | 9.67 | 0.00 | **0.43** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **1.01** | **1.26** | 1.55 | 2.28 | **9.14** |
| Rhode-2 | 1.94 | 0.00 | 0.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **1.60** | **1.70** | 1.12 | 2.52 | **10.07** |
| Rhode-3 | 1.76 | 0.00 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **1.81** | **1.96** | 1.11 | 2.35 | **11.09** |
| Rhode-4 | 0.55 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.22 | **1.25** | **1.37** | 1.14 | 2.35 | **9.79** |
| Severn-1 | 5.27 | 0.13 | **0.87** | 0.00 | 0.00 | 0.12 | 0.00 | 0.00 | 0.00 | **1.35** | **1.88** | 2.41 | 3.54 | **12.54** |
| Severn-2 | 40.36 | 0.00 | **1.29** | 0.00 | 0.00 | 0.05 | 0.06 | 0.00 | 0.00 | **1.38** | **2.91** | 4.47 | 4.82 | **20.33*** |
| Severn-3 | 12.24 | 0.00 | **1.30** | 0.00 | 0.00 | 0.20 | 0.00 | 0.07 | 0.00 | **1.53** | **8.47*** | 6.26 | 6.03 | **31.27*** |
| CBBH | 3.93 | 0.00 | 0.16 | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.50 | 0.52 | 1.95 |
| CBBO | 3.29 | 0.00 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | **0.70** | 0.74 | 1.11 | **4.50** |
| CBCP | 0.15 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.39 | 0.40 | 1.31 |
| CBMP | 5.37 | 0.00 | 0.23 | 0.00 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.25 | 0.55 | 0.78 | 1.23 | **4.23** |
| CBSB | 7.26 | 0.00 | 0.12 | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.50 | 0.62 | 1.69 |

Notes: Bold, concentrations above the EPA Subsistence Fishers Screening Value; Bold*, concentrations above the EPA Recreational Fishers Screening Value; no concentrations were above the FDA Action or Tolerance Level.

[a] Also known as Gamma-hexachlorocyclohexane or Gamma-HCH.

[b] The EPA recommendeds that tissue samples be analyzed for benzo(a)pyrene and 14 other PAHs (Acenaphthene, Acenaphthylene, Anthracene, Benz(a)anthracene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Benzo(g,h,i)perylene, Chrysene, Dibenz(a,h)anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-cd)pyrene, Phenanthrene, Pyrene) and that that a potency-weighted total concentration be calculated for each sample for comparison with the recommended SVs for benzo(a)pyrene.

[c] The total concentration of cis- and trans-chlordane, cis- and trans-nonachlor and oxychlordane.

[d] The total concentration of 4,4'- and 2,4'-DDT and their 4,4' and 2,4'-DDE and DDD metabolites.

[e] EPA recommends that 18 congeners be summed to determine total PCB concentration (8,18,28,44,52,66,77,101,105,118,126,128,138,153,169,170,180,187).

Appendix 6. Individual contaminant concentrations in oyster tissue per site in the Chesapeake Bay, MD (ng/dry g).

| Compound | CBCT-1 | CBCT-2 | CBCT-3 | CBCT-4 | CBPT-1 | CBPT-2 | CBPT-3 | CBPT-4 | CBRD-1 | CBRD-2 | CBRD-3 | CBRD-4 | CBSV-1 | CBSV-2 | CBSV-3 | CBBH | CBBO | CBCP | CBMP | CBSB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Monobutyltin | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.11 | 0 | 0 | 0 | 2.73 | 10.93 | 5.56 | 3.62 | 3.57 | 0 | 2.8 | 3.18 |
| Dibutyltin | 0 | 0 | 3.19 | 2.59 | 5.83 | 7.75 | 5.91 | 10 | 21.4 | 7.49 | 6.73 | 3.02 | 10.5 | 50.3 | 21.8 | 18.4 | 19 | 0 | 22.5 | 21.6 |
| Tributyltin | 1.74 | 1.5 | 0 | 2.3 | 12.8 | 9.75 | 12.6 | 6.02 | 65.4 | 14.3 | 12.2 | 3.34 | 32.9 | 266 | 85 | 56.6 | 43.5 | 0 | 71 | 78 |
| Tetrabutyltin | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | | | | | | | | | | |
| Heptachlor | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Heptachlor-Epoxide | 0 | 0.47 | 0 | 0 | 2.01 | 2.99 | 4.49 | 5.16 | 0 | 0 | 0 | 0 | 0.72 | 0.33 | 1.41 | 0.59 | 0 | 0 | 0.81 | 0.44 |
| Oxychlordane | 0 | 0 | 0 | 0 | 1.67 | 0 | 2.25 | 5.3 | 0 | 0 | 0 | 0 | 0 | 0.46 | 0 | 0 | 0 | 0 | 0 | 0 |
| Alpha-Chlordane | 2.11 | 1.73 | 2.98 | 0 | 16.78 | 17.62 | 27.2 | 67.18 | 2.91 | 2.4 | 2.28 | 1.94 | 4.04 | 8.38 | 11.86 | 1.81 | 2.72 | 0.93 | 2.87 | 1.37 |
| Gamma-Chlordane | 1.73 | 1.4 | 2.14 | 1.28 | 12.45 | 16.14 | 25.43 | 61.35 | 2.03 | 1.9 | 1.67 | 1.71 | 2.76 | 5.91 | 9.38 | 2.6 | 2.75 | 2.02 | 3.21 | 1.91 |
| Trans-Nonachlor | 2.2 | 2.78 | 3.58 | 2.46 | 15.83 | 12.91 | 18.92 | 52.76 | 3.62 | 2.29 | 2.17 | 2.09 | 5.54 | 9.55 | 14.11 | 1.97 | 2.78 | 1.38 | 2.42 | 1.53 |
| Cis-Nonachlor | 1.05 | 1.24 | 1.99 | 1.05 | 5.72 | 6.69 | 7.19 | 22.39 | 1.92 | 1.7 | 1.61 | 1.23 | 2.68 | 5.14 | 8.12 | 0.86 | 1.59 | 0.61 | 1.78 | 0.52 |
| | | | | | | | | | | | | | | | | | | | | |
| 1,2,3,4-Tetrachlorobenzene | 0 | 0 | 0 | 2.8 | 0 | 0 | 0 | 0 | 1.4 | 0 | 2.11 | 0 | 0 | 1.1 | 0 | 0 | 0 | 0 | 3.15 | 0 |
| 1,2,4,5-Tetrachlorobenzene | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hexachlorobenzene | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.39 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pentachloroanisole | 1.87 | 1.84 | 0 | 0 | 1.98 | 2.9 | 4.66 | 6.45 | 0 | 0 | 0 | 0 | 0 | 0 | 4.75 | 2.12 | 2.14 | 1.88 | 1.53 | 1.55 |
| Pentachlorobenzene | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | | | | | | | | | | |
| 2,4'-DDD | 0 | 0 | 0 | 0 | 5.83 | 1.89 | 11.03 | 29.49 | 1.66 | 4.3 | 1.74 | 0 | 5.26 | 6.81 | 9.89 | 1.69 | 3.41 | 0 | 3.99 | 1.17 |
| 4,4'-DDD | 0.98 | 2.11 | 2.59 | 0 | 6.48 | 4.08 | 13.08 | 102.15 | 2.71 | 0 | 0 | 2.02 | 2.92 | 5.86 | 7.78 | 1.46 | 2.96 | 0.76 | 2.83 | 0.83 |
| 2,4'-DDE | 0.61 | 0.6 | 0.72 | 1.15 | 1 | 0.34 | 2.06 | 1.31 | 0.94 | 1.1 | 0.84 | 0.51 | 0.84 | 1 | 1.15 | 0 | 0.83 | 0 | 0.88 | 0 |
| 4,4'-DDE | 13.44 | 9.67 | 23.02 | 5.73 | 21.43 | 15.37 | 30.4 | 52.85 | 9.33 | 12.42 | 13 | 11.81 | 13.04 | 17.37 | 22.36 | 4.41 | 7.52 | 4.31 | 8.52 | 4.04 |
| 2,4'-DDT | 0 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0.76 | 0.79 | 0.75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.62 |
| 4,4'-DDT | 0 | 0 | 0.34 | 0.29 | 0 | 0 | 1.57 | 2.74 | 0 | 0 | 0 | 0 | 0 | 0.74 | 0.72 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | | | | | | | | | | |
| Aldrin | 0 | 0 | 0 | 0 | 2.21 | 2.05 | 0 | 4.13 | 0 | 0 | 0 | 0 | 0.84 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dieldrin | 1.1 | 1.68 | 2.14 | 1.71 | 15.04 | 14.7 | 24.91 | 35.45 | 2.89 | 1.96 | 2.09 | 0 | 5.42 | 8.52 | 9.04 | 2.26 | 2.31 | 1.24 | 3.03 | 1.32 |
| Endrin | 0 | 0 | 0 | 0 | 0 | 0.43 | 0.68 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | | | | | | | | | | |
| Endosulfan I | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Endosulfan II | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Endosulfan Sulfate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | | | | | | | | | | |
| Alpha-HCH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Beta-HCH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Delta-HCH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gamma-HCH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.48 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | | | | | | | | | | |
| Mirex | 0 | 2.51 | 0 | 0 | 0 | 0 | 2.48 | 2.56 | 0 | 0 | 0 | 1.32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix 6: Individual contaminant concentrations in oyster tissue per site in the Chesapeake Bay, MD (ng/dry g).

| Compound | CBCT-1 | CBCT-2 | CBCT-3 | CBCT-4 | CBPT-1 | CBPT-2 | CBPT-3 | CBPT-4 | CBRD-1 | CBRD-2 | CBRD-3 | CBRD-4 | CBSV-1 | CBSV-2 | CBSV-3 | CBBH | CBBO | CBCP | CBMP | CBSB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Acenaphthene | 24.9 | 0 | 0 | 19.9 | 22.6 | 0 | 8.36 | 38.1 | 3.11 | 19.6 | 0 | 0 | 2.79 | 16.98 | 5.56 | 3.62 | 3.57 | 0 | 2.8 | 12.8 |
| Acenaphthylene | 2.15 | 2.39 | 3.51 | 16.1 | 13.6 | 8.16 | 6.98 | 13.6 | 5 | 2.25 | 3.63 | 2.15 | 4.78 | 9.62 | 15.6 | 0 | 4.6 | 0 | 3.9 | 0 |
| Anthracene | 6.99 | 9.87 | 10 | 81 | 51.2 | 33.4 | 35.4 | 107 | 14.6 | 7.86 | 9 | 8.32 | 15.3 | 36.3 | 49.3 | 3.55 | 9.34 | 2.04 | 9.51 | 1.45 |
| Benz(a)anthracene | 2.6 | 3.58 | 3.09 | 31.5 | 85.6 | 28.9 | 26.5 | 108 | 6.14 | 3.75 | 3.65 | 2.8 | 9.23 | 35.3 | 50.6 | 0 | 8.88 | 1.94 | 7.82 | 1.43 |
| Benzo(a)fluoranthene | 1.16 | 1.76 | 0 | 5.34 | 12 | 6.61 | 5.22 | 13.9 | 3.88 | 0 | 0 | 0 | 3.02 | 9.37 | 0 | 0 | 3.5 | 0 | 0 | 0 |
| Benzo(a)pyrene | 2.35 | 4.73 | 17.6 | 14.8 | 18.2 | 9.33 | 8.13 | 16.4 | 6.84 | 11.8 | 12.6 | 7.63 | 8.4 | 9.11 | 10.6 | 0 | 3.97 | 0 | 3.27 | 0 |
| Benzo(b)fluoranthene | 7.75 | 8.79 | 7.46 | 38.2 | 112 | 106 | 68.9 | 206 | 10.4 | 5.44 | 6.69 | 3.7 | 16.6 | 61.8 | 153 | 4.01 | 31.3 | 4.01 | 24 | 4.11 |
| Benzo(e)pyrene | 2.73 | 2.76 | 2.98 | 15.3 | 48.8 | 42.8 | 38.3 | 91.3 | 4.81 | 2.67 | 3.47 | 1.44 | 7.43 | 26.4 | 75.7 | 2.68 | 23 | 2.14 | 17.4 | 2.02 |
| Benzo(g,h,i)perylene | 1.41 | 1.24 | 2.63 | 2.67 | 13.6 | 12.1 | 8.85 | 20 | 2.72 | 1.87 | 1.57 | 15.2 | 2.41 | 6.9 | 19.4 | 0 | 9.06 | 0 | 6.37 | 0 |
| Benzo(k,j)fluoranthene | 1.38 | 1.52 | 1.3 | 6.26 | 23.9 | 21.2 | 8.48 | 35 | 2.5 | 0 | 1.08 | 0 | 2.34 | 9.26 | 31.7 | 0 | 6.2 | 0 | 4.99 | 0 |
| Benzothiophene | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Biphenyl | 0 | 0 | 0 | 6.72 | 0 | 0 | 0 | 8.02 | 0 | 0 | 0 | 6.11 | 4.65 | 4.67 | 5.17 | 0 | 0 | 0 | 0 | 0 |
| C1-Benzothiophenes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C1-Chrysenes | 0 | 0 | 0 | 0 | 34.5 | 29 | 5.94 | 75.1 | 0 | 0 | 0 | 0 | 4.5 | 11.4 | 33.7 | 0 | 0 | 0 | 0 | 0 |
| C1-Decalins | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C1-Dibenzo(a,h)anthracenes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C1-Dibenzothiophenes | 0 | 0 | 0 | 1.29 | 4.03 | 0 | 9.21 | 19.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C1-Fluoranthenes/Pyrenes | 4.96 | 5.28 | 4.21 | 39.2 | 108 | 65.7 | 60.1 | 203 | 8.74 | 4.28 | 6.54 | 3.14 | 19.4 | 55.2 | 114 | 0 | 15.1 | 0 | 11.5 | 0 |
| C1-Fluorenes | 0 | 0 | 0 | 4.84 | 9.68 | 14 | 0 | 45.1 | 0 | 0 | 0 | 0 | 8.52 | 0 | 26.4 | 0 | 0 | 0 | 0 | 0 |
| C1-Naphthalenes | 3.34 | 2.82 | 5.63 | 9.18 | 10.6 | 4.9 | 4.48 | 7.32 | 4.42 | 5.75 | 5.11 | 5.14 | 5.58 | 4.91 | 9.48 | 5.27 | 7.63 | 3.44 | 7.53 | 3.33 |
| C1-Naphthobenzothiophenes | 0 | 0 | 0 | 3.32 | 11.1 | 17.8 | 22.2 | 39.7 | 0 | 0 | 0 | 0 | 1.92 | 4.22 | 12.7 | 0 | 0 | 0 | 3.1 | 0 |
| C1-Phenanthrenes/Anthracenes | 4.03 | 3.26 | 0 | 22.4 | 40.3 | 27.1 | 32.6 | 103 | 5.44 | 4.05 | 4.61 | 4.35 | 16.8 | 21.5 | 35.5 | 3.79 | 11 | 2.48 | 9.34 | 2.5 |
| C2-Benzothiophenes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C2-Chrysenes | 0 | 0 | 0 | 0 | 10 | 14.4 | 19 | 17.2 | 0 | 0 | 0 | 0 | 0 | 0 | 9.73 | 0 | 0 | 0 | 0 | 0 |
| C2-Decalins | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C2-Dibenzo(a,h)anthracenes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C2-Dibenzothiophenes | 0 | 0 | 0 | 0 | 13.8 | 0 | 39.7 | 65.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.35 | 0 |
| C2-Fluoranthenes/Pyrenes | 0 | 0 | 0 | 7.8 | 33.8 | 27.9 | 29.1 | 52.7 | 0 | 0 | 0 | 0 | 5.22 | 14.9 | 27 | 0 | 5.11 | 0 | 0 | 0 |
| C2-Fluorenes | 0 | 0 | 0 | 0 | 29.3 | 56.4 | 0 | 97.4 | 0 | 0 | 0 | 0 | 31 | 0 | 81 | 0 | 0 | 0 | 0 | 0 |
| C2-Naphthalenes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C2-Naphthobenzothiophenes | 0 | 0 | 0 | 0 | 7.03 | 24 | 29 | 32.2 | 0 | 0 | 0 | 0 | 0 | 2.86 | 10.6 | 0 | 0 | 0 | 0 | 0 |
| C2-Phenanthrenes/Anthracenes | 13.6 | 0 | 0 | 19.8 | 52.5 | 67.9 | 61 | 145 | 0 | 0 | 0 | 0 | 29.1 | 32 | 71.9 | 0 | 19.8 | 0 | 10.3 | 4.95 |
| C3-Benzothiophenes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C3-Chrysenes | 0 | 0 | 0 | 0 | 0 | 7.61 | 10 | 12.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C3-Decalins | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C3-Dibenzo(a,h)anthracenes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C3-Dibenzothiophenes | 0 | 0 | 0 | 0 | 14.9 | 47.8 | 66.4 | 73.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.84 | 0 |
| C3-Fluoranthenes/Pyrenes | 0 | 0 | 0 | 2.49 | 9.46 | 25.8 | 30.2 | 21.3 | 0 | 0 | 0 | 0 | 3.59 | 5.64 | 17.1 | 0 | 0 | 0 | 0 | 0 |
| C3-Fluorenes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 137 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C3-Naphthalenes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 55 | 0 | 0 | 0 | 0 | 27 | 0 | 32.5 | 0 | 0 | 0 | 0 | 0 |
| C3-Naphthobenzothiophenes | 0 | 0 | 0 | 0 | 5.97 | 18 | 16.9 | 20.4 | 0 | 0 | 0 | 0 | 1.43 | 3.03 | 10.1 | 0 | 0 | 0 | 0 | 0 |
| C3-Phenanthrenes/Anthracenes | 0 | 0 | 0 | 5.69 | 41.7 | 90.7 | 84.2 | 121 | 0 | 0 | 0 | 0 | 18.1 | 27.5 | 63.2 | 0 | 11.4 | 0 | 8.35 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix 6: Individual contaminant concentrations in oyster tissue per site in the Chesapeake Bay, MD (ng/dry g).

| Compound | CBCT-1 | CBCT-2 | CBCT-3 | CBCT-4 | CBPT-1 | CBPT-2 | CBPT-3 | CBPT-4 | CBRD-1 | CBRD-2 | CBRD-3 | CBRD-4 | CBSV-1 | CBSV-2 | CBSV-3 | CBBH | CBBO | CBCR | CBMP | CBSB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C3-Phenanthrenes/Anthracenes | 0 | 0 | 0 | 5.69 | 41.7 | 90.7 | 84.2 | 121 | 0 | 0 | 0 | 0 | 18.1 | 27.5 | 63.2 | 0 | 11.4 | 0 | 8.35 | 0 |
| Monobutyltin | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.11 | 0 | 0 | 0 | 2.73 | 10.93 | 5.56 | 3.62 | 3.57 | 0 | 2.8 | 3.18 |
| C4-Benzothiophenes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C4-Chrysenes | 0 | 0 | 0 | 0 | 0 | 0 | 4.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C4-Decalins | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C4-Dibenzothiophenes | 0 | 0 | 0 | 0 | 6.68 | 60.7 | 59.1 | 32.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C4-Fluoranthenes/Pyrenes | 0 | 0 | 0 | 0 | 5.49 | 13.6 | 13.4 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 4.48 | 0 | 0 | 0 | 0 | 0 |
| C4-Naphthalenes | 0 | 0 | 0 | 0 | 0 | 0 | 33.5 | 41.5 | 0 | 0 | 0 | 0 | 28.8 | 0 | 54.6 | 0 | 0 | 0 | 0 | 0 |
| C4-Naphthobenzothiophenes | 0 | 0 | 0 | 0 | 1.5 | 0 | 5.11 | 5.16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C4-Phenanthrenes/Anthracenes | 0 | 0 | 0 | 0 | 16.5 | 119 | 90.9 | 104 | 0 | 0 | 0 | 0 | 13 | 11.6 | 32 | 0 | 0 | 0 | 0 | 0 |
| Carbazole | 4.23 | 4.94 | 4.92 | 8.2 | 5.82 | 6.03 | 7.67 | 12.2 | 2.69 | 4.32 | 4.18 | 3.29 | 3.43 | 3.45 | 10.1 | 0 | 0 | 0 | 0 | 0 |
| Chrysene/Triphenylene | 4.06 | 7.06 | 4.75 | 51.9 | 173 | 73.9 | 74.2 | 214 | 10.8 | 4.22 | 5.27 | 3.48 | 21.8 | 85.7 | 147 | 0 | 23.4 | 3.8 | 18.4 | 4.28 |
| cis/trans Decalin | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dibenzo(a,h)anthracene | 0 | 0 | 0 | 0 | 3.58 | 2.84 | 2.19 | 4.16 | 0 | 0 | 0 | 0 | 0 | 0 | 4.68 | 0 | 0 | 0 | 0 | 0 |
| Dibenzofuran | 0 | 2.86 | 3.21 | 26.3 | 15.19 | 4.43 | 9.39 | 30.69 | 4.33 | 4.09 | 3.21 | 4.79 | 3.83 | 7.22 | 5.38 | 5.34 | 5.94 | 3.86 | 4.67 | 3.68 |
| Dibenzothiophene | 0 | 0 | 0 | 5 | 4.74 | 0 | 2.66 | 10.3 | 0.784 | 0.689 | 0.613 | 1.13 | 0.811 | 1.21 | 1.16 | 0.746 | 1.51 | 0 | 1.36 | 0 |
| Fluoranthene | 9.93 | 10.1 | 8.93 | 108 | 179 | 123.3 | 102 | 344 | 10.8 | 5.83 | 10 | 5.34 | 23.9 | 99.3 | 250 | 6.77 | 41.2 | 6.15 | 29.3 | 9.64 |
| Fluorene | 1.44 | 2.51 | 2.46 | 33.1 | 20.9 | 4.84 | 12.4 | 54 | 4.1 | 11.1 | 1.96 | 2.8 | 2.9 | 6.43 | 2.46 | 4.17 | 5.01 | 2.57 | 4.96 | 2.37 |
| Indeno(1,2,3-c,d)pyrene | 0 | 0 | 0 | 2.2 | 8.43 | 5.64 | 3.76 | 7.76 | 0 | 0 | 0 | 0 | 1.29 | 3.63 | 10.3 | 0 | 5.5 | 0 | 4.04 | 0 |
| Naphthalene | 0 | 0 | 14.9 | 15.4 | 20.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12.6 | 0 | 21.9 | 0 | 0 | 0 | 0 | 0 |
| Naphthobenzothiophene | 0 | 0 | 0 | 12.8 | 52.4 | 17.2 | 19 | 68.3 | 0 | 0 | 0 | 0 | 7.05 | 17.1 | 35.5 | 0 | 0 | 0 | 4.44 | 0 |
| Perylene | 0 | 0 | 0 | 0 | 20.5 | 8.95 | 13.1 | 33.4 | 0 | 0 | 0 | 9.14 | 0 | 0 | 10.6 | 0 | 17.7 | 0 | 12.3 | 0 |
| Phenanthrene | 2.38 | 4.33 | 2.95 | 86.8 | 66.9 | 8.66 | 13.7 | 103 | 6.9 | 4.58 | 3.8 | 6.87 | 8.47 | 13.3 | 7.45 | 6.59 | 12.2 | 0 | 11.6 | 4.35 |
| Pyrene | 5.82 | 3.69 | 3.93 | 40.6 | 86.5 | 51.1 | 51.5 | 166 | 5.64 | 3.85 | 5.8 | 2.99 | 12.2 | 47.8 | 132 | 4.66 | 31.2 | 3.21 | 17.9 | 3.1 |
| | | | | | | | | | | | | | | | | | | | | |
| PCB1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB101/90 | 5.49 | 5.41 | 8.31 | 3.52 | 30.38 | 35.88 | 52.32 | 64.63 | 9.71 | 12.33 | 13.51 | 7.57 | 10.85 | 22.77 | 40.49 | 5.02 | 9.44 | 2.95 | 9.45 | 3.35 |
| PCB105 | 0.7 | 0 | 1.6 | 0.63 | 2.88 | 6.87 | 4.35 | 8.28 | 1.3 | 1.35 | 0 | 1.37 | 1.65 | 2.65 | 4.97 | 0 | 0.97 | 0 | 0 | 0 |
| PCB107 | 0 | 0 | 0 | 0 | 50.5 | 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13.64 | 0 | 20.94 | 0 | 17.92 | 0 |
| PCB110/77 | 3.18 | 3.57 | 5.96 | 1.11 | 19.39 | 30.68 | 35.15 | 52.86 | 6.84 | 8.06 | 7.27 | 4.92 | 7.39 | 15.66 | 28.15 | 2.24 | 5.18 | 0.71 | 5.33 | 1.12 |
| PCB114/131/122 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB118 | 3.25 | 2.93 | 5.84 | 2.86 | 13.32 | 24.98 | 23 | 38.52 | 4.68 | 5.65 | 6.25 | 4.79 | 5.02 | 12.36 | 22.42 | 2.55 | 3.28 | 1.88 | 3.7 | 1.71 |
| PCB126 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB128 | 0 | 0 | 0.99 | 0 | 1.94 | 2.89 | 1.76 | 5.83 | 0.9 | 0.96 | 0.93 | 1.01 | 0.57 | 1.34 | 2.57 | 0 | 1 | 0 | 0.97 | 0 |
| PCB129/126 | 0 | 0 | 1.21 | 1.86 | 1.37 | 1.68 | 2.07 | 1.07 | 1.19 | 2.44 | 1.91 | 1.87 | 1.13 | 6.84 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB136 | 0 | 0 | 0 | 0 | 0 | 0 | 3.42 | 2.71 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB138/160 | 2.79 | 2.51 | 4.28 | 0 | 20.56 | 25.25 | 36.26 | 44.9 | 6.06 | 7.44 | 7.18 | 5.35 | 9.23 | 15.95 | 24.95 | 3.37 | 7.68 | 1.6 | 7.7 | 2.26 |
| PCB141/179 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB146 | 0 | 0 | 0 | 0 | 9.27 | 6.99 | 0 | 18.56 | 0 | 0 | 0 | 0 | 0 | 7.22 | 0 | 0 | 3.25 | 0 | 2.63 | 0 |
| PCB149/123 | 2.6 | 2.39 | 4.9 | 3.17 | 20.38 | 16.98 | 37.1 | 30.29 | 8.09 | 8.86 | 9.64 | 5.67 | 10.8 | 18.24 | 25 | 3.93 | 8.85 | 2.59 | 9.01 | 2.34 |
| PCB15 | 0 | 0 | 0 | 0 | 3.3 | 11.15 | 5.5 | 14.68 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB151 | 3.11 | 2.89 | 3.2 | 0 | 8.64 | 11.25 | 18.82 | 18.26 | 3.62 | 5.92 | 4.72 | 4.63 | 5.57 | 6.4 | 10.82 | 1.69 | 2.61 | 0 | 3.11 | 1.15 |
| PCB153/132 | 5.26 | 4.77 | 7.67 | 5.39 | 40.01 | 39.87 | 72.6 | 75.16 | 13.3 | 17.04 | 15.9 | 9.47 | 20.5 | 34.59 | 49.81 | 8 | 17.54 | 4.46 | 17.3 | 5.71 |

## Appendix 6: Individual contaminant concentrations in oyster tissue per site in the Chesapeake Bay, MD (ng/dry g).

| Compound | CBCT-1 | CBCT-2 | CBCT-3 | CBCT-4 | CBPT-1 | CBPT-2 | CBPT-3 | CBPT-4 | CBRD-1 | CBRD-2 | CBRD-3 | CBRD-4 | CBSV-1 | CBSV-2 | CBSV-3 | CBBH | CBBO | CBCP | CBMP | CBSB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Monobromobiphenyl | 0 | 0 | 0 | 0 | 3.26 | 2.34 | 6.32 | 6.69 | 3.11 | 0 | 0 | 0 | 2.71 | 10.98 | 4.56 | 3.62 | 3.57 | 0 | 2.88 | 3.18 |
| PCB156/171/202 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.14 | 0 | 4.62 | 0 | 0 | 0 | 2.81 | 0 |
| PCB158 | 0 | 0 | 0 | 0 | 0 | 0 | 0.76 | 1.32 | 0 | 0 | 0 | 0 | 0 | 0 | 0.76 | 0 | 0 | 0 | 0 | 0 |
| PCB16/32 | 0 | 0 | 0 | 0 | 2.18 | 3.77 | 0 | 5.82 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB166 | 11.87 | 8.11 | 1.09 | 0 | 7.08 | 3.87 | 12.99 | 10.02 | 0.73 | 1.51 | 1.62 | 0 | 0 | 0 | 3.77 | 0 | 0 | 0 | 0 | 0 |
| PCB167 | 0 | 0 | 0 | 0 | 0.87 | 0.99 | 1.16 | 1.96 | 0 | 0 | 0 | 0 | 0 | 0.92 | 1.31 | 0 | 0 | 0 | 0 | 0 |
| PCB169 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB170/190 | 0 | 0 | 0 | 0 | 1.93 | 1.54 | 2.57 | 2.2 | 0 | 0 | 0 | 0 | 0.69 | 1.08 | 1.81 | 0 | 1.16 | 0 | 0.88 | 0 |
| PCB172 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB174 | 0 | 0 | 0 | 0 | 0.69 | 0.38 | 1.13 | 1.07 | 0 | 0 | 0 | 0 | 0 | 0 | 0.68 | 0 | 0 | 0 | 0 | 0 |
| PCB176/137 | 0 | 0.54 | 0 | 0 | 0.57 | 0.64 | 0 | 1.51 | 0 | 0.57 | 0 | 0 | 0 | 0 | 0.65 | 0 | 0 | 0 | 0 | 0 |
| PCB177 | 0.79 | 0.67 | 0.48 | 0.43 | 3.92 | 4.11 | 7.7 | 6.09 | 1 | 1.11 | 1.19 | 1.78 | 2.03 | 2.78 | 4.16 | 0 | 1.84 | 0 | 1.91 | 0 |
| PCB178 | 0 | 0 | 0 | 0 | 2.91 | 1.6 | 5.58 | 2.98 | 0.96 | 0.94 | 0.94 | 0.44 | 1.5 | 2.26 | 2.44 | 0 | 1.47 | 0 | 1.46 | 0 |
| PCB18 | 0 | 0 | 0 | 0 | 4.97 | 9.62 | 5.33 | 13.52 | 0 | 0 | 0 | 0 | 0 | 0 | 3.24 | 1.98 | 1.88 | 1.77 | 0 | 0 |
| PCB180 | 0.62 | 0.77 | 0 | 0 | 4.14 | 2.67 | 0 | 15.66 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.97 | 0 | 0 | 0 |
| PCB183 | 0 | 0 | 0 | 0 | 1.71 | 1.56 | 3.87 | 3.26 | 0.53 | 0.69 | 0.64 | 0 | 0.89 | 1.23 | 2.1 | 0 | 1.09 | 0 | 1.03 | 0 |
| PCB185 | 0 | 0 | 0 | 0 | 1.22 | 0.77 | 0.91 | 1.12 | 0 | 0 | 0 | 0 | 0 | 0 | 1.33 | 0 | 0 | 0 | 0 | 0 |
| PCB187 | 2.23 | 2.49 | 3.8 | 3.78 | 14.21 | 11.25 | 31.75 | 18.89 | 6.27 | 7.62 | 8.36 | 3.59 | 8.96 | 12.45 | 17.63 | 3.79 | 8.3 | 1.65 | 8.06 | 2.33 |
| PCB189 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB191 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB194 | 0 | 0 | 0 | 0 | 0 | 0 | 0.9 | 0.46 | 0 | 0 | 0 | 0 | 0 | 0 | 0.64 | 0 | 0 | 0 | 0 | 0 |
| PCB195/208 | 0 | 0 | 0 | 0 | 0 | 0 | 0.37 | 0.55 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB196/203 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB199 | 0 | 0 | 0 | 0 | 1.05 | 0.62 | 1.76 | 1.08 | 0 | 0 | 0 | 0 | 0.63 | 0.75 | 0.87 | 0 | 0 | 0 | 0 | 0 |
| PCB200 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB201/157/173 | 0 | 2.38 | 0 | 0 | 0 | 0 | 2.03 | 2.93 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.67 | 0 | 0 | 0 |
| PCB205 | 0 | 0 | 0.95 | 0 | 0 | 0.84 | 1.66 | 1.23 | 0 | 0 | 0 | 0 | 0 | 0.45 | 0 | 0 | 0 | 0 | 0.74 | 0 |
| PCB206 | 0 | 0 | 0 | 0 | 0.55 | 0 | 0.87 | 0 | 0 | 0 | 5.28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB209 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.88 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB22/51 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 2.96 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB24/27 | 0 | 0 | 0 | 0 | 0.59 | 0.8 | 0.87 | 1.75 | 0 | 0 | 0 | 0 | 0 | 0 | 0.66 | 0 | 0 | 0 | 0 | 0 |
| PCB25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.29 | 0 |
| PCB26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.63 | 0 |
| PCB28 | 17.33 | 14.09 | 11.5 | 11.79 | 13.52 | 29.93 | 24.91 | 31.93 | 11.54 | 14.11 | 15.09 | 17.74 | 14.75 | 8.46 | 16.51 | 0 | 0 | 1.11 | 1.65 | 1.53 |
| PCB29 | 0.7 | 0.87 | 0 | 0 | 0.39 | 0 | 0 | 0.4 | 0 | 1.36 | 0 | 1.13 | 0 | 0 | 0 | 0 | 0 | 0 | 0.81 | 0 |
| PCB31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB33/53/20 | 1.21 | 1.43 | 0 | 0 | 2.79 | 9 | 3.29 | 6.52 | 0 | 0 | 1.56 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.96 | 0 |
| PCB40 | 0 | 0 | 0 | 0 | 2.92 | 9.77 | 0 | 8.4 | 0 | 0 | 0 | 0 | 2.48 | 2.61 | 2.71 | 1.58 | 0 | 1.42 | 1.94 | 0 |
| PCB41/64 | 0 | 0.87 | 0 | 0 | 7.32 | 16.56 | 8.16 | 19.75 | 0 | 0 | 0 | 0 | 0.92 | 2.12 | 6 | 0 | 0.92 | 0 | 0 | 0 |
| PCB42/59/37 | 0.5 | 0 | 0.77 | 0 | 5.72 | 10.49 | 8.4 | 15.49 | 0 | 0 | 2.07 | 0 | 1.04 | 2.3 | 8.03 | 0 | 1.07 | 0 | 1.23 | 0 |
| PCB43 | 0 | 0 | 0 | 0 | 0 | 2.63 | 0 | 1.91 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB44 | 0.9 | 1.71 | 1.45 | 0 | 11.89 | 25.19 | 18.15 | 30.19 | 2.56 | 2.11 | 2.61 | 3.4 | 0 | 5.03 | 0 | 0.98 | 1.96 | 0 | 1.95 | 0 |
| PCB45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix 6: Individual contaminant concentrations in oyster tissue per site in the Chesapeake Bay, MD (ng/dry g).

| Compound | CBCT-1 | CBCT-2 | CBCT-3 | CBCT-4 | CBPT-1 | CBPT-2 | CBPT-3 | CBPT-4 | CBRD-1 | CBRD-2 | CBRD-3 | CBRD-4 | CBSV-1 | CBSV-2 | CBSV-3 | CBBH | CBBO | CBCB | CBMB | CBSB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PCB44 | 0.9 | 1.71 | 1.45 | 0 | 14.89 | 25.12 | 18.15 | 30.19 | 2.56 | 2.11 | 2.61 | 3.4 | 0 | 5.05 | 0 | 0.98 | 1.96 | 0 | 1.95 | 0 |
| Monobutyltin | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.14 | 0 | 0 | 0 | 2.73 | 10.93 | 5.56 | 3.62 | 3.57 | 0 | 2.8 | 3.18 |
| PCB45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB46 | 0 | 0 | 0 | 0 | 0 | 0 | 5.42 | 5.36 | 0 | 0 | 0 | 0 | 0 | 3.97 | 0 | 0 | 0 | 0 | 6.13 | 3.88 |
| PCB47/48/75 | 7.11 | 7.36 | 3.47 | 0 | 18.21 | 25.59 | 38.51 | 33.58 | 3.27 | 5.7 | 5.04 | 4.57 | 6.49 | 7.7 | 18.88 | 0 | 0 | 0 | 0 | 0 |
| PCB49 | 0 | 2.25 | 3.28 | 0.94 | 18 | 27.03 | 31.69 | 40.22 | 3.63 | 5.18 | 5.36 | 3.23 | 3.88 | 8.92 | 22.76 | 0 | 3.34 | 0 | 3.12 | 0.86 |
| PCB52 | 3 | 3.74 | 2.12 | 2.67 | 21.64 | 33.38 | 34.52 | 49.63 | 5.49 | 5.8 | 7.28 | 5.38 | 6.01 | 13.77 | 24.06 | 2.36 | 4.26 | 1.17 | 4.27 | 1.28 |
| PCB56/60 | 0 | 0 | 0 | 0 | 0 | 28.02 | 3.74 | 19.11 | 0 | 0 | 0 | 0 | 0 | 1.08 | 3.74 | 0 | 0 | 0 | 0 | 0 |
| PCB66 | 1.11 | 0.7 | 1.15 | 0 | 5.87 | 19.43 | 7.35 | 14.62 | 0 | 0 | 0 | 0 | 0 | 3.52 | 8.7 | 0 | 0 | 0 | 0 | 0 |
| PCB7/9 | 0 | 0 | 0 | 2.11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.98 | 5.79 | 3.72 | 4.88 | 3.18 |
| PCB70 | 1.23 | 0 | 2.39 | 0 | 10.12 | 28.17 | 19.99 | 31.97 | 0 | 0 | 2.69 | 0 | 0 | 6.52 | 13.67 | 1.32 | 2.15 | 0 | 2.34 | 0.92 |
| PCB74/61 | 1.24 | 0.79 | 0.78 | 0 | 6.97 | 19.9 | 10.75 | 18.1 | 2.44 | 2.54 | 1.98 | 0 | 1.86 | 3.3 | 8.91 | 1.64 | 1.25 | 1.43 | 2.37 | 0.89 |
| PCB77 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB8/5 | 6.5 | 2.17 | 0 | 0 | 3.13 | 10.75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB81 | 0 | 0 | 1.68 | 3.2 | 0 | 0 | 0 | 0 | 0 | 2.72 | 2.86 | 3.62 | 1.68 | 0.84 | 0.73 | 0 | 0 | 0 | 0 | 0 |
| PCB82 | 0 | 0 | 2.1 | 0 | 0 | 6.91 | 0 | 0 | 0 | 0 | 0 | 0 | 4.46 | 0 | 7.06 | 0 | 0 | 0 | 0 | 0 |
| PCB83 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7.01 | 0 | 0 | 0 | 0 | 0 | 0.86 | 2.84 | 0 | 0 | 0 | 0 | 0 |
| PCB84 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB85 | 2.41 | 2.08 | 1.33 | 1.04 | 3.75 | 9.56 | 4.81 | 10.46 | 1.46 | 2.47 | 2.49 | 2.26 | 2.38 | 2.01 | 5.04 | 0 | 0 | 0 | 1.1 | 0 |
| PCB86 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PCB87/115 | 0.78 | 0.77 | 0.84 | 0.4 | 3.25 | 10.73 | 4.97 | 19.81 | 1.15 | 1.04 | 0.96 | 0.86 | 1.22 | 3.1 | 4.46 | 0.88 | 1.48 | 0.71 | 1.25 | 0.89 |
| PCB88 | 2.1 | 1.2 | 1.28 | 0 | 11 | 13.69 | 17.96 | 24.4 | 3.33 | 0 | 0 | 0 | 2.34 | 7.01 | 13.63 | 1.92 | 0 | 1.17 | 3.1 | 1.43 |
| PCB92 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| PCB95 | 2.87 | 3.53 | 5.29 | 0 | 19.67 | 21.22 | 36.27 | 47.22 | 0 | 0 | 0 | 0 | 0 | 14.64 | 24.46 | 0 | 0 | 0 | 0 | 0 |
| PCB97 | 1.92 | 1.51 | 2.83 | 0.86 | 8.45 | 11.94 | 13.05 | 21.64 | 2.73 | 3.29 | 3.37 | 2.26 | 2.64 | 6.6 | 12.64 | 1.24 | 2.3 | 0 | 2.23 | 0.76 |
| PCB99 | 4.46 | 4.41 | 7.17 | 4.17 | 19.14 | 19.72 | 31.05 | 32.79 | 6.37 | 9.54 | 10.19 | 6 | 7.36 | 15.93 | 29.13 | 2.19 | 5.45 | 2.04 | 5.42 | 1.79 |

Notes: DDT, dichlorodiphenyltrichloroethane; DDD, dichlorodiphenyldichloroethane; DDE, dichlorodiphenyldichloroethylene; HCH, hexachlorocyclohexane; PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl

Notes: DDT, dichlorodiphenyltrichloroethane; DDD, dichlorodiphenyldichloroethane; DDE, dichlorodiphenyldichloroethylene; HCH, hexachlorocyclohexane; PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl

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